DEGREE PROJECT

Energy performance of built heritage in the subarctic climate zone of northern Sweden

Applying existing standards and methodologies for improving energy efficiency of built heritage

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Energiprestanda hos kulturhistorisk bebyggelse i subarktisk klimatzon i norra Sverige
Applicering av standarder och metodologi för förbättring av energieffektivitet i kulturhistorisk bebyggelse

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Omslagsbild: Puoitakvägen från början av 1900-talet
Källa: *Gällivare Bildarkiv* och *Hermelin 50-60 tal "Dokumentera Malmberget"* publicerad av Studiefrämjandet
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Petter Vilhelmsson

Abstract

In Sweden, as well as in Europe, buildings are estimated to consume 40 % of the total energy use. Moreover, one third of the European building stock consists of buildings with some sort of distinguable cultural or historic significance, and it follows logically that a considerable percentage of Sweden's and Europe's total energy is consumed by this category of buildings – historic buildings. Especially when considering that historic buildings typically have inferior energy performance than other buildings. The challenge to improve the energy performance in historic buildings while also taking heritage values into consideration is undertaken within the scope of this master's thesis. The European standard *"Conservation of cultural heritage – Guidelines for improving the energy performance of historic buildings"* (SS-EN 16883:2017) is partially applied to a case-building in order to approach the challenge methodically.

The energy performance of a building and proposed refurbishment measures is evaluated through the use of computer-generated building energy models. Three different scenarios with sets of refurbishment measures have been simulated; (1) light impact, (2) moderate impact and (3) heavy impact on heritage values. Categorization of the refurbishment measures have been accomplished by using an objectivistic approach based on contemporary conservation theories and definitions. The theoretical framework is primarily based on conservation practices laid out by the Burra Charter.

The light refurbishment package would reduce the heating energy use by almost 11 % while having little to no impact on the building's heritage values. The moderate package would reduce the heating energy use by 34,5 % without having a major impact on the building's heritage values. The most invasive refurbishment package would, the heavy refurbishment package, would reduce the heating energy use by almost 40 %. This significant energy use reduction would not come without its drawbacks. This package of measures would infact alter some of the expressed character defining elements of the building.

Improving the energy efficiency of built heritage is a challenge, especially when trying to assess the impact it might have on its heritage values. This master's thesis can provide some insight into the act of balancing energy improvement measures and cultural heritage values against one another, especially for buildings that lack formal protection in the form of legislative directives or policies.

Keywords: Cultural heritage, cultural value assessment, energy improvement, energy performance, refurbishment measures

Sammanfattning

I Sverige, såsom i övriga Europa, uppskattas byggnader stå för 40 % av den totala energianvändningen. En tredjedel av europeiska byggnader har någon form av kulturell eller historisk betydelse. Detta tyder på att en betydelsefull andel av Sveriges och Europas totala energi förbrukas av denna kategori byggnader – historiska byggnader. I synnerhet när hänsyn tas till att historiska byggnader i allmänhet påvisar sämre energiprestanda än andra byggnader. Utmaningen att förbättra energiprestandan i historiska byggnader samtidigt som man respekterar och beaktar kulturvärden behandlas inom ramen för detta examensarbete. Den europeiska standarden *"Bevarande av kulturarv - Riktlinjer för förbättring av energiprestandan i historiska byggnader"* (SS-EN 16883: 2017) tillämpas delvis på en byggnad för att på ett metodiskt tillvägagångssätt angripa utmaningen.

Byggnadens energiprestanda och föreslagna renoveringsåtgärder utvärderas genom användning och analys av datorgenererade energimodeller. Tre scenarier, bestående av olika renoveringsåtgärder med varierande påverkan av kulturvärdena har simulerats; (1) lätt påverkan, (2) måttlig påverkan och (3) stor påverkan av kulturvärden. Kategoriseringen av renoveringsåtgärderna har uppnåtts genom att använda ett objektivistiskt tillvägagångssätt baserat på rådande definitioner och kunskap från byggnadsmiljövården. Den teoretiska referensramen är huvudsakligen baserad på bevarandepraxis som fastställts i Burra-stadgan.

Renoveringspaketet med ”lätt påverkan” skulle minska användningen av värmeenergi med nästintill 11 % samtidigt som åtgärden har liten eller ingen betydande inverkan på byggnadens kulturvärden. Det ”måttliga paketet” skulle kunna minska användningen av värmeenergi med 34,5 % utan att ha en alltför stor inverkan på byggnadens kulturvärden. Det mest omfattande renoveringspaketet som innebär ”stor påverkan” skulle kunna minska användningen av värmeenergi med nästan 40 %. Denna betydande förbättring kommer inte utan tillhörande nackdelar. Detta paket av åtgärder kan potentiellt skada eller förändra karaktären hos byggnaden. Karaktärsdrag som uttryckligen bedömts vara värda att bevara.

Att förbättra energieffektiviteten hos kulturhistorisk bebyggelse är en utmaning, särskilt när man försöker bedöma vilken påverkan eventuella åtgärder kan ha på ovärderliga kulturvärden. Detta examensarbete kan ge viss insikt i hur man kan balansera energibesparingsåtgärder och kulturvärden mot varandra, särskilt för byggnader som saknar särskilt uttryckta skyddsåtgärder i form av byggnadsminnesförklaring, lagstiftning eller politiska ställningstaganden.

Nyckelord: Energibesparing, energiprestanda, kulturarv, kulturvärdesbedömning, renoveringsåtgärder

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Abbreviations

ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BBR	Boverket's building regulations (Boverkets byggregler)
CEN	The European Committee for Standardization
EU	European Union
EU-28	The European Union is a political and economic union of 28 member states that are located primarily in Europe.
EFFESUS	Energy Efficiency for EU Historic Urban Districts' Sustanability
FEC	Final energy consumption covers the energy supplied to the final consumer for all energy uses. It is calculated as the sum of the final energy consumption of all sectors. Final energy consumption is typically measured in million tonnes of oil equivalent (Mtoe).
GHG	A greenhouse gas contributes to the greenhouse effect by absorbing and emitting infrared radiation. Carbon dioxide, methane and water vapour are all examples of common greenhouse gases.
IDA ICE	IDA Indoor Climate and Energy is a building performance simulation software. The software models the building and its associated subsystems in order to evaluate energy consumption and overall performance.
LKAB	Luossavaara-Kiirunavaara Aktiebolag
PBL	The Swedish Planning and Building Act, Plan- och bygglagen (2010:900)
PEC	Primary energy consumption measures the accumulated energy consumption of a region, usually a county. The measurement takes the consumption of the energy sector itself into account. Transformation and distribution losses are also included, as is the direct energy use at the source.
RAÄ	The Swedish National Heritage Board (Riksantikvarieämbetet)
SVEBY	Standardize and verify energy performance of buildings (Standardisera och verifiera energiprestanda för byggnader)
SCB	Statistics Sweden (Statistiska Centralbyrån)
UNFCCC	United Nations Framework Convention on Climate Change

Definitions

Place	The term, as defined by the Burra Charter, has a broad scope. It includes natural and cultural features as well as individual buildings and groups of buildings.
The building's energy use	The term is defined according to BBR as the energy which, in normal use during a reference year, needs to be supplied *(E_{bea})* to a building for heating (E_{uppv}), comfort cooling (E_{kyl}), domestic hot water (E_{tvv}) and the building's property energy and/or electricity E_f (also referred to as "facility emergy"). The building's energy use is calculated using the following equation: $$E_{bea} = E_{uppv} + E_{kyl} + E_{tvv} + E_f$$
The building's property energy	The term is defined according to BBR as the share of the building electricity consumption that is related to the building's operational needs, where the electricity consuming appliance is located in, under or affixed to the exterior of the building. This includes permanently installed light fixtures in common spaces and utility rooms. It also includes energy used in heating cables, pumps, fans, motors, control and monitoring equipment etc. Externally locally placed devices that supply the building, such as pumps and fans for free cooling, are also included. Appliances intended for use other than for the building, such as engine and compartment heaters for vehicles, battery chargers for external users, lighting in gardens and walkways, are not included.
Domestic energy (E_t)	The term is defined according to BBR as electricity or other form of energy consumed for domestic purposes. Examples of this are electricity consumption for dishwashers, washing machines, dryers (also in shared laundry rooms), stoves, fridges, freezers, and other household appliances and lighting, computers, TVs and other consumer electronics and the like.
Domestic hot water (E_{tvv})	Water consumed by occupants of any building, for domestic purposes. The energy for heating of water is part of the building's energy use and is included in the requirement for the building's primary energy value.
Energy for comfort cooling (E_{kyl})	The term is defined according to BBR as the cooling or the amount of energy supplied to the building used to reduce the indoor temperature for human comfort. Cooling energy that is extracted directly from the environment without coolers from sea water, fresh air or the like (known as free cooling) is not included.
Indoor temperature	Temperature set-point intended to be maintained indoors (in temperature-controlled spaces) by heating, ventilation and air conditioning systems when the building is performing its required function.
A_f	Total area for windows, gates, doors and comparable elements. Expressed in square meters (m^2).
A_{om}	Sum of the enclosing surface area of all individual elements of the building envelope in direct contact with heated indoor air (m^2).
A_{temp}	The term is defined by BBR as the area enclosed by the inside of the building envelope of all storeys including cellars and attics for temperature-controlled spaces are intended to be heated to more than 10 °C. The area occupied by interior walls, openings for stairs, shafts, etc., are included. The area for garages, within residential buildings or other building premises other than garages, are not included.
Primary energy value (EP_{pet})	A value which designates a building's energy performance (kWh/A_{temp} and year).

Thermal transmittance (U-value)

Thermal transmittance (W/m^2K), is the rate of transfer of heat (W = J/s) through one square meter of a structure, divided by the difference in temperature across the structure. The thermal transmittance can be derived from the equation below:

$$Q = A \cdot U \cdot (T_1 - T_2)$$

where Q is the heat transfer in Watts or Joules per second, A is the area, and $T_1 - T_2$ is the difference between the indoor and outdoor temperature.

U_m

The average thermal transmittance for structural elements and thermal bridges (W/m^2K) as determined by SS-EN ISO 13789:2017 and SS 24230 (2). The average thermal transmittance is calculated using the equation below:

$$U_m = \frac{\left(\sum_{i=1}^{n} U_i A_i + \sum_{k=1}^{m} l_k \Psi_k + \sum_{j=1}^{p} \chi_j\right)}{A_{om}}$$

Pa

Pascal is used to quantify internal pressure. It is defined as one newton per square meter.

R

Thermal resistance is a measurement of a temperature difference by which material resists a heat flow. It is defined as the thermal resistance of unit area of a material.

Z

Water vapour resistance is a measurement of how resistive a material is to vapour infiltration (s/m)

Roman lowercase letters

c

Specific heat capacity is defined as the quantity of heat per unit mass required to raise the temperature by one degree Celsius (J/kgK)

Greek lowercase letters

ρ

Volumetric density is defined as the mass divided by the volume (kg/m^3)

Φ

Heat flow rate between two systems is measured in joules per second (W)

ψ

Linear thermal transmittance is the measure of heat loss related to linear thermal bridges per (W/mK)

χ

Heat flow rate divided by the temperature difference for one dimensional thermal bridges is also known as the point thermal transmittance (W/K)

λ

Thermal conductivity is a measurement of a material's property to conduct heat (W/mK)

δ

Water vapour permeability/diffusivity is defined as the property of materials that determine the rate at which vapour passes through it due to differences in pressure (m^2/s).

1 Background and introduction

1.1 International climate and energy framework

The ultimate goal of the 1992 United Nations Framework Convention on Climate Change (UNFCCC) is to counteract global warming by reducing greenhouse gas (GHG) concentrations in the atmosphere to *"a level that would prevent dangerous anthropogenic interference with the climate system",* as stated in Article 2 of the protocol. Revisions to the protocol have defined two commitment periods. The first period ended 2012 and the second period ends in 2020 and serves as a bridge for the post-2020 global climate change agreement (European Commision, 2016). During the second commitment period, the protocol presents binding targets for most European countries (members of EU-28). Targets include the reduction of GHG emissions by 20 % by the end of 2020 from the 1990 levels.

More recent climate and energy frameworks propose even more ambitious targets. The Paris agreement, for example, states that the GHG emission reduction target ought to be at least 40 % by 2030 from the 1990 levels. As of July 2018, 194 states and the EU have ratified the Agreement. EU, however, has encouraged its member states to develop national climate and energy legislation. The 2030 climate and energy framework were approved by the leaders of the union during 2014 and is the continuation and advancement of the Europe 2020 strategy. The climate and energy framework primarily emphasize on sustainable growth. Sustainable growth is defined as the promotion of resource-efficient, eco-friendly and viable markets. To achieve the envisioned outcome of the strategy, three key climate and energy targets have been formulated by the EU for the year 2030 (European Union, 2017):

- At least a 40 % reduction in GHG emissions (from 1990 levels);
- At least a 27 % share of renewable energy in gross final energy consumption (FEC);
- At least 27 or 30 % improvement in energy efficiency (depending on the Commission's proposal for an altered energy efficiency directive).

1.1.1 Milestones and current progression towards the 2020 climate and energy targets

The EU, and its member states, are well on their way to achieve the goal of a 20 % reduction of GHG emissions by 2020 from the 1990 levels. In 2015, GHG emissions were cut by 22.1 %. Effectively, already accomplishing that objective (European Union, 2017).

Non-fossil and renewable fuels need to have a bigger impact on our energy consumption. In 2015, non-fossil fuels accounted for 16.7 % of gross final energy consumption, 3.3 percentage points short of the goal of at least a 20 % share of gross final energy consumption from non-fossil fuels. Non-fossil fuels are projected to increase during the remained of the decade, and the goal will most likely be reached.

The target regarding final energy efficiency for 2020 has already been achieved, but with respect to primary energy consumption (PEC), the EU must reduce it an additional 3.1 % between 2015 and 2020 (European Union, 2017).

1.1.2 The residential sector and its contribution to the final energy consumption

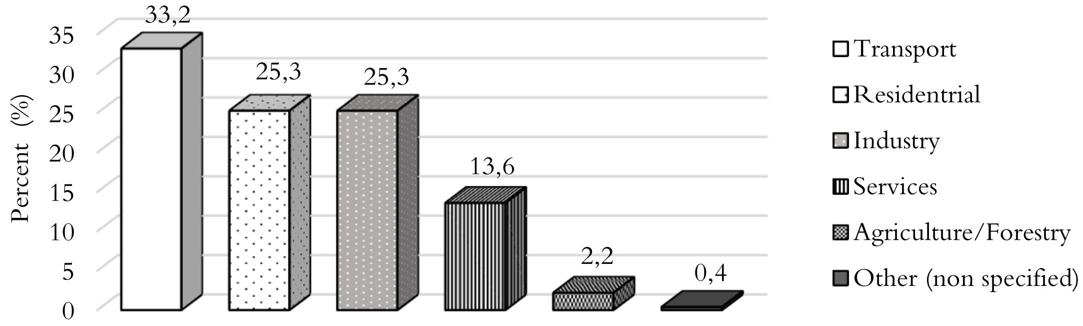


Figure 1. Percentage of FEC by sector, percent of FEC (Data source: European Union, 2017, p. 102).

Approximately one fourth of the final energy consumption (FEC) in the EU is associated with the residential sector alone (figure 1). Comparable statistics are available from 2015 for Swedish energy consumption. These statistics also indicate that the residential sector accounts for roughly 1/4 of the FEC (Swedish Energy Agency, 2018). To achieve the increasingly demanding long-term climate ambitions, considerable energy performance improvements in the residential sector is essential. Consequently, this includes heritage and culturally significant buildings. A substantial part of European buildings is considered to be a part of the cultural heritage. In Sweden, approximately one third of buildings built before 1945 constitutes an important part of the country's built heritage (European Commission, 2010), These types of historic buildings generally have worse energy performance than other buildings and thus account for a considerable part of the FEC.

1.1.3 Legislation surrounding energy improvements of cultural heritage

Energy strategies and programs in Europe encompasses all types of buildings, including heritage and culturally significant buildings (Directive 2010/31/EU; Directive 2012/27/EU). However, exemptions have been made for buildings which have been deemed worthy of conservation. Exemptions that exclude certain buildings with architectural, historical and/or cultural values from energy reduction requirements. These exemptions are in place as a measure for the protection of the built heritage (EU 2002/91/EC, EPBD).

The Swedish Planning and Building Act (PBL) (SFS 2010:900) specifically states that a building experiencing alteration or relocation can be exempted from the energy management and thermal insulation requirements (SFS 2010:900, chapter 8, section 7). Furthermore, a limitation against distortion is prescribed by law. The limitation states that a building which is particularly valuable from a historic, cultural-historical heritage, environmental or artistic point of view may not be distorted (SFS 2010:900, chapter 8, section 13). Alterations to buildings and moving of buildings must be carried out with care, so that the building's characteristics are taken into consideration and its technical, historical, cultural-historical heritage, environmental and artistic values are protected (SFS 2010: 900, chapter 8, section 17). These sections of PBL directly mirrors the previously mentioned EU directive and legislative framework.

1.1.4 Initiatives and projects

The Swedish Energy Agency (Miljö- och energidepartementet) has initiated the research project *Save and Preserve* (Spara och bevara) to improve the energy efficiency of historic buildings without distorting cultural values. *Energy Efficiency for EU Historic Urban Districts' Sustanability"* (EFFESUS) is a similar research project directed by the EU. *Efficient Energy for EU Cultural Heritage (3ENCULT)* was a project co-funded by the European Union Seventh Framework Programme and carried out between 2010 and 2014. The project had as its intended goal to "bridge the gap between conservation of historic buildings and climate protection". All of these mentioned projects state, in some manner, the importance of energy efficiency improvements of historic buildings or districts if national and international climate and energy targets are going to be achieved. Although the topic has been and is being researched it is obvious that continued research is essential in order to formulate new energy policies in regard to built heritage and its preservation.

1.2 Aim, objective, scope and boundaries of the project

The general topic of this master's thesis is to answer the following research question: ***to what extent can the energy efficiency of culturally significant buildings be improved without damaging or affecting their intrinsic cultural and aesthetical values?***

The research question can be more precisely stated as: how extensively do energy-saving measures affect cultural heritage values of one specific building in the northern parts of Sweden? Another question which will be answered is: what type of refurbishment measures are suitable for a historic building of this type? Another part of the master's thesis is thus to ***purpose viable refurbishment measures*** which are applicable, at least theoretically, to the building described in section 3.2 in an effort to improve its energy performance while simultaneously preserve its heritage values.

The case study is limited to one building in the community of Malmberget, Gällivare. The building has been labeled "Arbetarbostäder 158" (directly translated as: Workers Quarters' 158) by LKAB Fastigheter (regional property manager and a subdivision of LKAB).

The standard SS:EN 16883:2017 is used as the basis for how to approach the complex issue of improving energy efficiency of our built environment. Only specific parts of the standard have been applied (further limitations are presented in section 3.3). This standard does not specify how to perform the assessment of cultural heritage. The cultural value assessment is based on contemporary conservation theory and a statement of significance (concerning notable characteristics of the case-building) presented in section 2.1 and 3.2, respectively.

In order to evaluate the proposed refurbishment measures, there is a need to determine the baseline condition (i.e. reference performance or current condition) of the building. The energy efficiency of the proposed refurbishment measures is analysed in relation to the baseline condition. The chosen method for evaluating the efficiency (of the reference performance and the proposed energy-saving measures) is through the use of building energy performance simulations.

1.2.1 Problem statement and objective

Energy-saving measures can, if implemented improperly, damage or alter heritage values of a building. It subsequently follows that there is a necessity for both international and national legislation in order to ensure the continual preservation of our cultural heritage. The legislative stance allows for exemptions to be made from energy reduction requirements (as expressed by legislative bodies), as previously mentioned. It has furthermore been observed that exemptions have been used in order to circumvent problems (Pracchi, 2014). The over-utilization of exemptions is in direct conflict with the energy reduction requirements identified by the Swedish Energy Agency, 'EFFESUS' and '3ENCULT'.

The objective of this master's thesis is to provide a basis for the discussion regarding the energy improvement of heritage buildings with designated exemption status (exemption from energy improvement requirements). The research question (as stated in section 1.2 above) is put into the context of the case-building and its specific conditions. Thus, providing input into the discussion regarding the case-building's eventual refurbishment. The drawn conclusions regarding the case-building can, at least to a certain extent, also be considered to be valid for similar building types.

2 Theoretical framework and definitions

Terms, definitions and theory related to the conservation field are primarily provided by the *Australia ICOMOS Charter for Places of Cultural Significance 2013*. The document is more commonly referred to by its short title – *The Burra Charter*. It builds upon concepts previously defined by the International Council on Monuments and Sites (ICOMOS) and has been widely adopted as the standard guidelines for heritage conservation practice (Heritage Perth, 2011). Terms not defined by the Burra Charter are given by ICOMOS, Historic England, the Swedish National Heritage Board (RAÄ) and independent authors.

2.1 Conservation theory and principles

The Burra Charter defines conservation as *"all the processes of looking after a place so as to retain its cultural significance"*. Other definitions are more extensive, ICOMOS (1994) for example defines conservation as *"all efforts designed to understand cultural heritage, know its history and meaning, ensure its material safeguard and, as required, its presentation, restoration and enhancement"*. *Cultural significance* is defined by the Charter as *"aesthetic, historic, scientific, social or spiritual value for past, present or future generations"*. It is further stated that *"cultural significance is embodied in the place itself, its fabric, setting, use, associations, meanings, records, related places and related objects"*. The term cultural significance is synonymous with cultural heritage values and will be used interchangeably within the scope of this master's thesis. A *place* includes elements, objects, spaces and views (ICOMOS Austrailia, 2013, p. 2). This definition is rather comprehensive and naturally includes individual buildings as well.

Assesing the heritage values of a place or building immediately encounters conceptual and practical difficulties (The Getty Conservation Institute, 2002). These difficulties arise from the fact that these assessments are subjective and can be based on, for example, historical association, economics and artistic merit (The Getty Conservation Institute, 2002).

The rest of this section of the master's thesis will define terms and basic principles of which parts of the heritage value assessment is based on.

2.1.1 Reversibility

The term *reversibility* within the field of building conservation, in particular, means that a measure can be undone. In practice, this suggests that a building which has been altered can be returned to its previous condition. Changes and additions to buildings with heritage values should be as non-invasive as possible to original materials and constructions (Robertsson, 2002, p. 150). An encompassing interpretation of reversibility as a conservation measures is given by Historic England (2008): *"Our ability to judge the long-term impact of changes on the significance of a place is limited. Interventions may not perform as expected. As perceptions of significance evolve, future generations may not consider their effect on heritage values positive. It is therefore desirable that changes, for example those to improve energy efficiency in historic buildings, are capable of being reversed, in order not unduly to prejudice options for the future"*. This interpretation of reversibility is to a certain extent supported by article 15 clause 2 of the Burra Charter: *"Changes which reduce cultural significance should be reversible, and be reversed when circumstances permit"*. It is further stated by the charter that reversible changes should be considered temporary. Aspects of the longevity of changes are where the different interpretations of reversibility diverge from one another. Robertsson (2002) emphasizes the possibility of a change to be undone, whereas the Burra Charter more heavily emphasizes reversibility as the temporariness of a change.

2.1.2 Authenticity

The term *authenticity* is not defined once in the Burra Charter nor in its precursor the Venice Charter. However, contemporary conservation disciplines often refer to authentic values or character. Authenticity, in the context of this master's thesis, is interpreted as in the *Nara Document on Authenticity* as *"characteristics that most truthfully reflect and embody the cultural heritage values of a place"*. Authenticity is, in a more general sense, an object's ability to convey a sense of its own legitimacy.

Authenticity is primarily conveyed by materials and their condition; therefore, additional emphasis is given to original materials and their surfaces (Robertsson, 2002, p. 98). Traces of wear and tear on surfaces, contribute to the sense of historical proximity. This attribute is referred to as patina – a gloss or sheen on surfaces produced by the passage of time, use, etc. Later additions, maintenance and material layers can also foster a sense of credibility by providing evidence, in the form of historical layers, of its old age (Robertsson, 2002, p. 98).

Furthermore, authenticity is not limited to material substance only. It also includes intangible values as article 13 of the *Nara Document on Authenticity* state: *"Depending on the nature of the cultural heritage, its cultural context, and its evolution through time, authenticity judgements may be linked to the worth of a great variety of sources of information. Aspects of the sources may include form and design, materials and substance, use and function, traditions and techniques, location and setting, and spirit and feeling, and other internal and external factors".*

2.1.3 Restoration and reconstruction

Restoration means to re-establish hidden, disfigured or lost values to a previous or original state (Robertsson, 2002, p. 90). A similar definition of restoriation is expressed by the Burra Charter, it is stated as follows: "*returning a place to a known earlier state by removing accretions or by reassembling existing elements without the introduction of new material"*. Whereas conservation of existing fabric only attempts to eliminate sources of danger that directly threaten the fabric, restoration, on the other hand, is concerned with the overall appearance as historical and artistic evidence (Petzet, 2004, p. 10). Article 18 & 19 of the charter requires that: *"Restoration and reconstruction should reveal culturally significant aspects of the place"* and that "*restoration is appropriate only if there is sufficient evidence of an earlier state of the fabric*". These definitions and requirements significantly restrict the use of restoration as a conservation measure. Reconstruction is even more restricted according to article 20 clause 1 of the Burra Charter: *"Reconstruction is appropriate only where a place is incomplete through damage or alteration, and only where there is sufficient evidence to reproduce an earlier state of the fabric".*

2.1.4 Assessing heritage significance and managing change

A building, place or site of cultural significance require a systematic assessment approach, which is appropriate and proportionate to the scale, importance and purpose of the decision to be made. The following steps should be considered when change to cultural significance needs to be assessed (Historic England, 2008):

- ❖ Understand the fabric and evolution of the place
- ❖ Identify who values the place, and why
- ❖ Relate identified heritage values to the fabric of the place
- ❖ Consider the relative importance the heritage values
- ❖ Consider the contribution made by setting and context
- ❖ Compare the place with other places sharing similar values
- ❖ Articulate the significance of the place

the need for studies to understand the place. Studies which should include analysis of physical, documentary, and other evidence.

Steps to consider when making alterations to significant places

A part of conservation is to manage change to significant places by sustaining, revealing and reinforcing its cultural heritage values. When managing change the following steps (among others) should be considered (Historic England, 2008):

- Establish whether there is sufficient information
- Consider the effects on authenticity and integrity
- Take account of sustainability
- Consider the potential reversibility of changes
- Compare options and make the decision

2.2 The intersection between building conservation and energy efficiency

The following section of the master's thesis describes a recently developed standard approved by the European Committee for Standardization (CEN). The standard is namned "*Conservation of cultural heritage – Guidelines for improving the energy performance of historic buildings"* The standard suggests a procedural approach that can be applied to a wide variety of buildings regardless of value, age, formal protection, etc.

2.2.1 Guidelines for improving the energy efficiency of our built heritage

The Swedish and European standard *Conservation of cultural heritage – Guidelines for improving the energy performance of historic buildings* (hereby referred to simply as SS-EN 16883:2017) does not exclusively apply to historic buildings with statutorily designated cultural heritage. Generally, the standard will apply to a multitude and variety of situations where the priority is to find the balance between the energy performance and the conservation of its heritage values (SS-EN 16883:2017).

Understanding the building's authenticity, integrity, and heritage significance facilitates the process of defining the cultural and historic values (SS-EN 16883:2017). Any type of character altering interventions should be avoided. In fact, a generally healthy approach is to be cautious. An outcome can be considered successful if, as few and as uninvasive alterations as possible have been made to achieve the goal of the intervention (SS-EN 16883:2017). To achieve this, a multidisciplinary approach is needed. The team shall have general architectural and technical qualifications required for refurbishment projects. Team members should also have documented knowledge in work with historic buildings (SS-EN 16883:2017). However, The European committee for standardization (CEN) explicitly states in their "*Guidelines for improving the energy performance of historic buildings"* that the project team shall be scaled to suit the complexity of the project. For less complex projects and for minor interventions the project team may be reduced in size.

2.2.2 The process for improving the energy efficiency

SS-EN 16883:2017 presents a procedure to facilitate the decision-making process for improving the energy performance of culturally significant buildings. The process (figure 2) provides proficient guidance for making a well-informed and substantiated decision with emphasis on the specified objectives.

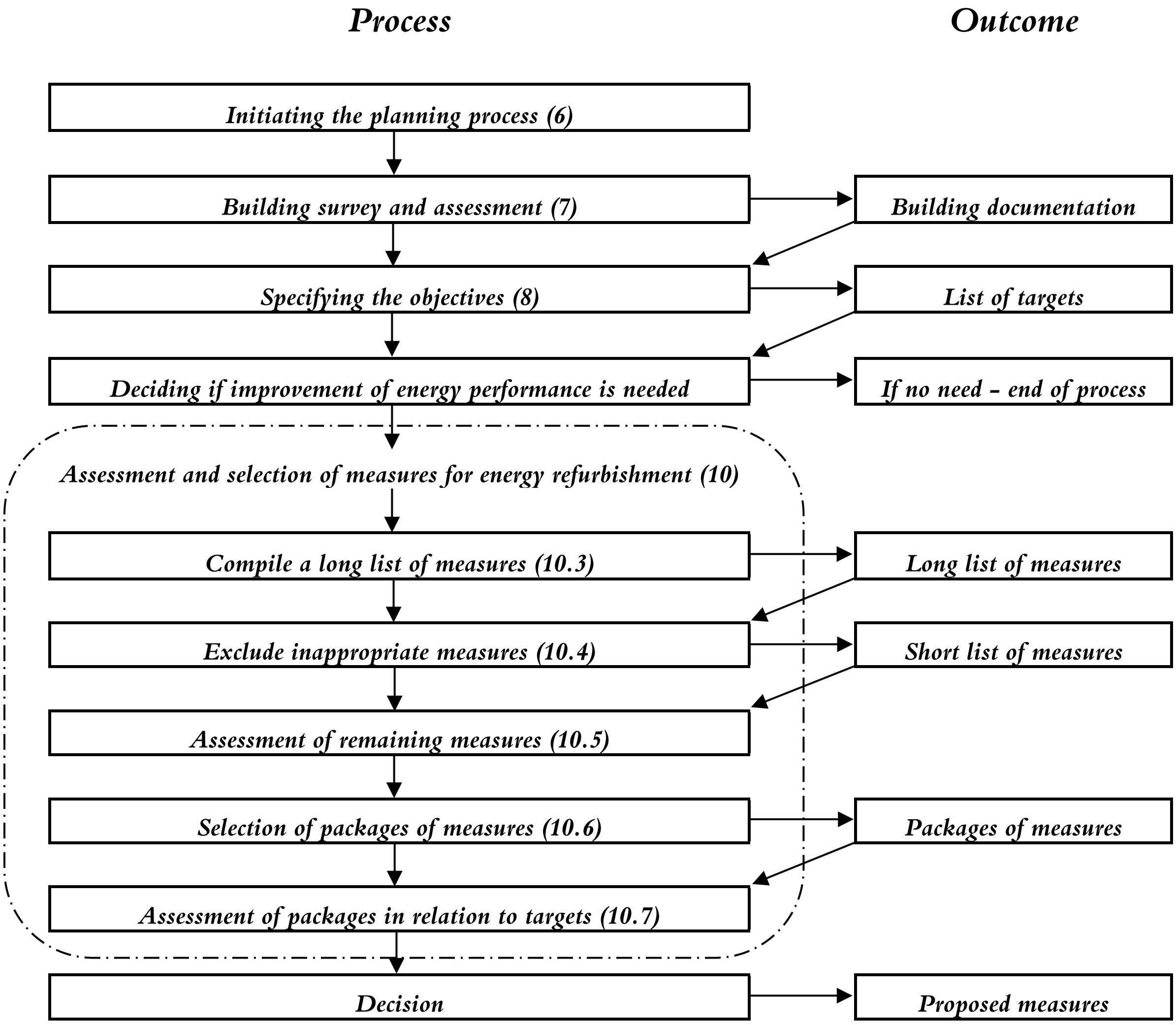


Figure 2. Flow chart describing the process step by step presented in SS-EN 16883:2017.

2.3 Building physics and the building as a system

2.3.1 Systems boundary and energy input/output

A building's energy use can be evaluated by considering the building itself as an open system, whose boundary is permeable to both energy and mass. By considering how the open system interacts with its surroundings an energy balance can be expressed as energy input and outputs (see figure 3 below). According to *Energy performance of buildings – Overall energy use and definition of energy ratings* (SS-EN 15603:2008) the system boundary corresponds to the meters for electricity, gas, district heating and water.

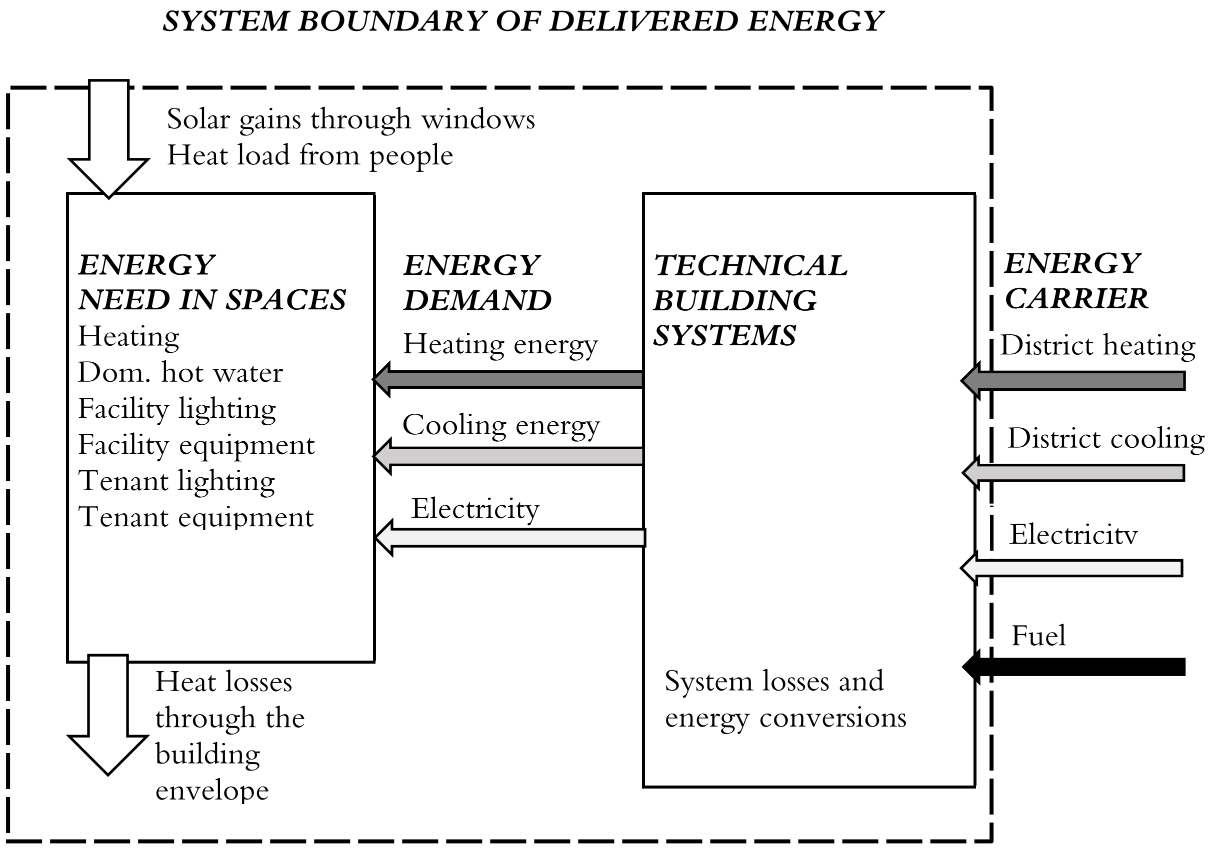


Figure 3. System boundary of delivered energy. Based on a figure produced by Kurnitski et al., (2011).

The energy balance (as illustrated in figure 3 above) is determined by both internal and external variables, many of which are stochastic. These variables include, but are not limited to, outdoor temperature, indoor temperature setpoints, domestic hot water usage, electricity demand, energy gains from solar radiation and heat load from people. When determining these types of variables studies, guidelines, approximations and average values are often used in an effort to as accurately as possible model realistic conditions. Also notice some of the similarities between figure 3 and equation 1.

2.3.2 *Boverket's building regulations – energy consumption and performance*

The National Board of Housing, Building and Planning (Boverket) is the central administrative authority for the built environment in Sweden. One of its most significant mandate is to manage the construction and administration of the building stock. Stipulations include among others access, design, dimentions, health and energy consumption.

BBR's mandatory provisions and general recommendations stipulates that buildings shall be designed to limit heat losses, cooling demands, electric loads, and the efficient management of these parameters.

Building's energy use

The building's energy use (E_{bea}) is defined by the following equation as:

$$E_{bea} = E_{uppv} + E_{kyl} + E_{tvv} + E_f \qquad \text{(Eq. 1)}$$

The energy which, in normal use during a reference year, needs to be supplied to a building (often referred to as "purchased energy" or "delivered energy") for heating (E_{uppv}) (kWh/year), comfort cooling (E_{kyl}) (kWh/year), hot tap water (E_{tvv}) (kWh/year) and the building's property energy (E_f). If underfloor heating, towel dryers or other devices for heating are installed, their energy use is also included (*Boverkets byggregler.*2017). This equation corresponds to the assessment of the annual energy used by a building according to standard *Energy performance of buildings – Overall energy use and definition of energy ratings* (SS-EN 15603:2008) (page 15).

Average thermal transmittance

Average thermal transmittance, according to BBR (*Boverkets Byggregler,* 2017), is calculated using the international standard *Thermal performance of buildings – Transmission and ventilation heat transfer coefficients – Calculation method (SS-EN ISO 13789:2007)* and the Swedish standard 24230:

$$U_m = \frac{\left(\sum_{i=1}^{n} U_i A_i + \sum_{k=1}^{m} l_k \Psi_k + \sum_{j=1}^{p} \chi_j\right)}{A_{om}} \qquad \text{(Eq. 2)}$$

The expression describes the average thermal transmittance (U_m) (W/m^{2}K) as the sum of the thermal transmittance for the all structural element times its respective area (U_iA_i), and the sum of all linear thermal bridges times their length ($\Psi_k l_k$), and the sum of all point shaped thermal bridges (χ_j). All of these different sums are added and divided by the total surface area of the building facing the heated indoor air (A_{om}).

Climate adjustment factors

Climate zones have been replaced in the most recent version of BBR by a geographical adjustment factor (F_{geo}) to better represent local climate conditions and more fairly represent comparable energy requirements of buildings, depending on their physical location. The geographical adjustment factor ranges between 0,9 for southern regions to 1,9 for the northernmost regions. This factor is used in equation 3 when determining a building's energy performance.

Energy carriers

There are a variety of forms energy can be stored in, these forms include: electric, solid, liquid and gaseous fuels. Furthermore, energy carriers can also describe an energy system that transfers energy. This would include district cooling and heating systems. Energy carriers are attributed an adjustment factor which effect the primary energy value with a factor of 1 or 1,6 depening on how energy is delivered to the building. The primary energy factor (PE_i) is a measurement of how efficient a natural resource is handled and produced before arriving at the end consumer. Electricity has a PE_i of 1,6 while other common energy carriers (biofuel, oil, gas, district heating and cooling) have a PE_i of 1,0 (*Boverkets Byggregler,* 2017). PE_i is one of the factors which affect the primary energy value, see equation 3.

Primary energy value

This value describes a buildings energy performance as a primary energy value (EP_{pet}):

$$EP_{pet} = \frac{\sum_{i=1}^{6}\left(\frac{E_{uppv,i}}{F_{geo}} + E_{kyl,i} + E_{tvv,i} + E_{f,i}\right) \cdot PE_i}{A_{temp}} \qquad \text{(Eq. 3)}$$

The primary energy value (EP_{pet}) is a measurement of a building's energy performance. It was introduced in BBR 1st of July 2017 (BFS 2017:5, BBR 25) as a result of an EU energy directive. EP_{pet} is mainly affected by the delivered energy ($E_{uppv,i}$, $E_{kyl,i}$, $E_{tvv,i}$, and $E_{f,i}$). Every energy carrier is weighted by a primary energy factor (PE_i). This factor tries to correct for the energy loss which occurs when delivering energy to the building. The sum of the delivered energy is divided by A_{temp}. EP_{pet} is usually expressed as kWh/m^2 and year.

Energy performance and average thermal transmittance

Newly constructed residential dwellings and non-residential premises shall be designed so that the parameters in table 1 do not exceed the given values (*Boverkets Byggregler,* 2017).

Table 1. Maximal allowed values for energy performance and average thermal transmittance for newly built dwellings.

Building classification and requirements	***Energy performance EP_{pet} (kWh/m^2 and year)***	***Average thermal transmittance (U_m) (W/m^{2}K)***
Dwellings		
Single-family houses	90	0,40
Single-family houses where A_{temp} is less than 50 m^2	No requirement	0,33
Multi-dwelling blocks	85	0,40

2.4 Framework and input data for energy performance simulations

SVEBY has collected and compiled standardized data for calculating and verifying energy performance of buildings in accordance to Boverkets byggregler (BBR). The input data should be used as a guidance for energy performance forecasting when developing contemporary multi-dwelling residential housing. However, the input data can be used for other types of buildings when appropriate (SVEBY, 2012).

Definition of property and household electricity

A building's facility electricity (E_f) is defined by BBR and SVEBY as the electricity needed for the building's installations and communal functions. The electricity needed to operate the central and technical systems of the building (for keeping the building functioning as intended). This includes, for example: fans, pumps, elevators and surface mounted lighting in communal spaces (SVEBY, 2012). Tenant energy is defined by BBR as electricity (or energy) for use by tenants in a household. The electric consumption of dishwashers, washing machines, drying equipment, freezers, refrigerators, stoves and other household appliances are all examples of tenant electricity (E_t). Included are also lighting, computers, televisions and other consumer electronics, see table 2 below. Tentant electricity is not included when calculating the energy performance of a building, facility electricity, on the other hand, is.

Table 2. Definitions and boundaries of what constitutes property and tenant (household) electricity for multi-dwelling (SVEBY, 2012, p. 9).

Definition	*Multi-dwelling blocks*	
	Facility electricity (E_f)	*Tenant electricity (E_t)*
Electricity for appliances in residential buildings (dishwasher, washing machine)		✓
Floor heating or equipment in sanitary room	✓	
Equipment in sanitary room (not including floor heating)		✓
Infra heat		✓
Engine warmer		✓
Laundry room (communal)		✓
Kitchen fan		✓
Outdoor lighting for fascade and entrance (even if the lightsource is place at a distance from the building)	✓	
Outdoor lighting for areas under larger canopies	✓	
Outdoor lighting for the surrounding area (within property limits)		✓
Outdoor lighting mounted on the fascade at entrances for separate apartments and their balconies		✓
Indoor lighting for residential apartments		✓
Indoor lighting for communal spaces (stairwells and basements)	✓	
Indoor lighting for communal spaces (laundry room and storage)	✓	
Electricity for elevator and elevator lighting	✓	
Electric heat for gutters, drain-pipes, surface water wells on roofs and terraces	✓	
Heatcables in the ground		✓
Electricity for pool or basin (private)		✓
Electricity for pool or basin (communal)		✓
Electricity for sauna heating unit		✓

2.4.1 *User affected input data and internal gains*

User affected input data consists of dynamic, stochastic and probabilistic factors. Some of these factors are: indoor temperature, internal gains from occupants, additional ventilation losses, heating energy for spaces and water, solar radiation etc. All these factors can, if not properly evaluated or approximated, lead to errors in the the energy model (Royapoor & Roskilly, 2015). Standard values for most of these factors are presented below.

Indoor temperature

When detailed or explicit temperature data are unavailable, it is common practice to use standardized values instead. The standard value for indoor temperature, when calculating the energy use of a building, is conventionally set to constrain the lower bound of the temperature. Recommended indoor temperature for both single family houses and multi-family dwelling blocks is 21 °C (SVEBY, 2012, p. 10).

The recommended temperature has been derived from several different studies. Two of which are Statens Institut för Byggnadsforskning (ELIB, 1992) and Hägerheds study of indoor environmental factors (Hägerhed-Engman, 2006). Both studies reveal similar results regarding the average indoor temperature of multi-family dwellings.

Internal gains from occupants

SCB and Hiller both conducted studies of how much time occupants spend at home during an average day. The SCB study states that the typical occupants spent 15,5 hours/day at their residence. However, Hillers results differed. 15,8 hours/day. After analyzing the average time spent at home during a whole week, the result was adjusted to 14 hours/day and person. As a result, SVEBY recommends a standardized value of 14,0 hours/day and person. The effect per occupant is recommended at a value of 80 W (SVEBY, 2012, p. 27).

Correction for additional ventilation losses

For multi-dwelling blocks the additional ventilation correction factor is 4 kWh/m^2 and year (SVEBY, 2012). This value is added to the results of the simulation. Many different variables are considered when determining the correction factor. Consequently, this value is a source for uncertainty in the results of a buildings energy performance (Eriksson & Wahlström, 2001). When the value 4 kWh/m^2 is converted to infiltration per building envelope area it equals 0,5 l/m s^2 at a pressure difference of 50 Pa. Correction for additional ventilation losses can be modeled as additional infiltration through the building envelope (SVEBY, 2012, p. 12).

Domestic hot water

A standard value for the domestic hot water consumption is 25 kWh/m^2 (A_{temp}). This is an average value for the energy required to increase water temperature during a normal year in an average multi-dwelling residence. Cold water temperature, outgoing hot water, armature, circulation and heat-losses all effect the energy requirement (SVEBY, 2012, p. 20). 20 % of the energy in the domestic hot water can be assumed to be distributed throughout the building as internal gains (Petersson, 2009).

Internal gains from light fixtures

Approximately 70 % of household electricity is converted to heat (SVEBY, 2012, p. 25). This recommendation is based on studies by Lövehed (1995), Sandberg (2005) alongside *Boverkets handbok Termiska Beräkningar* (2003).

2.4.2 Sun-shading

The sun-shading factor is partially dependent on behavioral patterns of occupants. The behavior in question is personal preference towards the use of sunshades and blinds. The factor is also, to an extent, dependent on direct shielding – the degree to which direct sunlight is blocked from going through the window. This occurs when objects, deliberately or not, are placed between a window and the directly incoming sunlight. Sun-shading is apart from direct shielding also dependent on the physical properties of the window. These properties determine how much of the radiation is reflected, absorbed and transmitted.

An average value for sun-shading has been determined to be 0,5 which means half of the incoming solar radiation is blocked, by some means, from going through the window. This value is adjusted and weighted by simultaneously considering both constant and stochastic variables (SVEBY, 2012, p. 18).

2.4.3 General framework for calculation of energy performance of buildings

EU Directive 2010/31/EU with associated annexes states that the energy performance of a building shall be determined on the basis of calculated or actual energy use and shall reflect typical energy use for space heating, space cooling, domestic hot water, ventilation, built-in lighting and other technical building systems. The directive further states that the energy performance of a building shall be expressed by a primary energy value (kWh/m^2 and year) for the purpose of both energy performance certification and compliance with minimum energy performance requirements.

The primary energy value shall be based on primary energy factors or weighting factors per energy carrier, which may be based on national, regional or local annual, and possibly also seasonal or monthly, weighted averages or on more specific information made available for individual district system. Primary energy factors or weighting factors shall be defined by Member States. In the application of those factors to the calculation of energy performance, Member States shall ensure that the optimal energy performance of the building envelope is pursued. When calculating the energy performance of buildings, the following aspects shall be taken into consideration: thermal characteristics, heating installation, hot water supply, air conditioning installations, natural and mechanical ventilation, lighting installations, design, positioning, orientation and location, solar systems and protection, indoor climate conditions and internal loads including cogeneration (Directive 2010/31/EU).

2.5 Insulation materials and recommendations for heritage buildings

Refurbishment measures with high impact on energy efficiency

Energy improvement measures in multi-family dwellings that reduces heat losses through the building envelope are often the most efficient ones (Abel & Elmroth, 2016). These results are achieved by improving the thermal resistance and the air leakage of the building envelope. Thermal resistance can be improved by additional insulating materials or by modifying the construction of building elements.

Exterior walls with low thermal resistance should, if otherwise acceptable, be especially considered for refurbishment as changes to thermally inefficient walls tend to yield the most substantial benefits in terms of energy-savings. Refurbishment measures along these lines can, under most circumstances, improve the energy performance of a building quite considerably (Liu, et.al, 2014). Additional insulation of the attic floor and/or roof is one of the single most efficient measures when improving a buildings energy performance (Abel & Elmroth, 2016). Air leakage can be improved by reducing the air flow through structural connections, windows and doors.

Performance of common insulation materials

Materials which are being considered for the proposed refurbishment measures are listed in table 3 below. The materials are ordered from lowest to highest performance. Thermal conductivity and vapour permeable ability as presented by Clarke et. al. (1990).

Table 3. Thermal conductivity of insulation materials according to Clarke et. al., (1990) and Petersson (2009). Properties of silica aerogel according to Baetens et. al., (2011).

Material	*Density (kg/m^3)*	*Water vapour permeability, δ_v ($10^{-6}m^2/s$)*	*Thermal conductivity, λ (W/mK)*	*Specific heat capacity, c_p (J/kgK)*	*Relative performance (scale: low, medium, high, very high)*
Wood wool board	400	10	0.085	1810	Very low
Wood fibre insulation board (external use)	140	Breathable	0,043	2100	Low
Cellolose fiber (CFI), loose-fill	21	11,4 – 14,2	0.042	2110	Low
Cellolose fiber (CFI, walls)	48	11,4 – 14,2	0,039	2110	Low
Mineral wool	200	8 – 12	0,040	800	Low
Mineral wool (floors)	20	8 – 12	0,036	800	Low
Mineral wool (walls)	125	8 – 12	0,033	800	Medium
Wood fibre insulation board (internal use)	50	Breathable	0,038	2100	Low
Mineral wool, loose-fill	15 27	15 – 24	0,036 0,042	800	Medium/low
Extruded polystyrene (XPS)	25	0,17 – 0,23	0,035	1500	Medium
Expanded polystyrene (EPS) board	20	0,9 – 1,4	0,036	1200	Medium
Polyurethane (PUR) board	35 – 45	0,28 – 1,1	0.025	1400 - 1500	High
Polyisocyanurate (PIR) board	32	~ 0	0,023 – 0,027	1400 - 1500	High
Silica aerogel	70 – 150	>1	0,014	1900 - 2300	Very high

2.5.1 Properties of insulation materials

The two most used forms of insulation used for improving the energy efficiency of heritage buildings are fiber and foam. Fiber insulation can be applied in a variety of forms; as batts (pads between studs), boards and loose-fill which can be blown in. Foam type insulation is also referred to as spray polyurethane foam (SPF), these foams vary in in material property. However, most foams display no water vapour permeable properties. The water vapour permeability (WVP) is the rate of which water vapour is transported through materials. This physical property determines the "breathability" of a material.

Wood wool boards

Wood wool boards display decent thermal insulating properties. The thermal conductivity highly correlates to compactness and density. Thermal conductivity usually ranges between 0.070 and 0.100 W/mK. At a density of 400 kg/m^3 the thermal conductivity is roughly 0.085 W/mK

(Johansson-Erik, 1994). Wood wool boards have the ability to absorb large amounts of water vapour. The water vapour permeability of wood wool boards are $10 \cdot 10^{-6}$ m^2/s (Johansson-Erik, 1994) The material also displays unusual properties for thermal insulation materials, wood wool boards attenuate the variations in air humidity by absorbing water vapour rapidly when the relative humidity rises and releasing water vapour when the relative humidity decreases (Johansson-Erik, 1994).

Cellulose fiber

Cellulose fibre insulation (CFI) is composed of paper fibres treated with inorganic additives, such as zinc borate, which acts as fire retardants. The additives also inhibit mould growth within the material. CFI can be blown into the construction by use of pneumatic equipment. The insulation is applied to construction cavities (space between studs or rafters). CFI can be used for both vertical and horizontal applications (Lopez, et.al, 2016). Lopez et. al states that the typical value for the thermal conductivity is 0.040 W/mK. The water vapour permeable property (table 3) of CFI would classify it as an excellent material in the category of breathable materials (Historic England, 2016b). As for the case with heritage buildings, where interior finishes are to be preserved, blown-in CFI is a suitable retrofit measure, Blown-in cellulose is also considered a reasonable preservation approach, since limited invasive action is required (Practical Conservation Guide for Heritage Properties, 2017, p. 8).

Wood fibre insulation boards

The thermal conductivity of wood fibre insulation boards range between 0.038 – 0.043 W/mK depending on format. Formats include boards for internal and external applications (Greenspec, 2018). Another feature of these boards is their 'breathability', which makes them a practical alternative for insulation in heritage buildings.

Expanded polystyrene boards

A rigid foamboard can be made from expanded polystyrene (EPS). As a result of the material's compactness, it is most commonly used in attics or on walls where there are space restrictions. EPS foam has pore structure, which restricts the air movement and heavily impacts the thermal conductivity of the material (0.030 W/mK, table 3). EPS boards can be used both externally and internally as insulation for walls, roofs and floors. EPS also exhibit slight water vapour permeable properties. With a water vapour permeability rate of $0{,}9 - 1{,}4 \cdot 10^{-6}$ m^2/s.

State-of-the art materials such as silica aerogels

Silica aerogels, hereby referred to as aerogels, have quite recently been produced for the consumer market. They have very high thermal performance in relation to traditional insulation materials. Aerogels are most commonly available as flexible blankets in thicknesses of 10 mm, they perform up to 2.5 times better than most traditional insulation materials (Baetens, et.al, 2011). Due to the relatively high cost, aerogels are mainly considered when there are space limitations. The water vapour permeability of aerogels (table 3) might allow them to be applied in older buildings, however the thermal performance will alter the hygrothermal conditions inside the wall, which warrants careful analysis of temperature and moisture distribution throughout the wall.

2.5.2 Internal, external or cavity insulation

Additional insulation of walls, roofs and floors can be done by three different methods, either by external insulation, internal insulation or by inserting insulation within the cavities (table 4). By applying one or more of these methods, the performance of the building element is altered. Problems with water vapour condensation can arise as a consequcence. Vapour barriers are normally not appropriate during the refurbishment of heritage buildings as they will not allow proper evaporation of moisture (Historic England, 2016a).

Table 4. The table is a summary of the three reports concerning insulation of heritage buildings (Historic England, 2016a; Historic England, 2016b; Historic England, 2016c).

Method	*Common application methods*	*Recommended materials*	*Advantages*	*Disadvantages*
External insulation	▪ Insulation layer fixed to the existing wall covered by a protective render or cladding	▪ Hemp-lime composites ▪ Glass fibre (mineral wool) ▪ Wood-fibre boards	▪ No alteration of the interior ▪ Increased weather resistance ▪ Provides additional thermal mass ▪ Does not reduce the floor area of rooms	▪ Affects the heritage values of the exterior ▪ Require adaptation of roof and wall junctions ▪ May require repositioning of windows ▪ Hygrothermal conditions are altered
Internal insulation	▪ Insulation is fixed directly to the internal wall and coated with a finish layer ▪ Installed with a ventilated cavity between the insulation and the wall. ▪ Rigid or non-rigid insulation between timber studs	▪ Almost any material ▪ Wood-fibre boards ▪ Sheep's wool batts ▪ Hemp-fibre batts ▪ Cellulose fibre	▪ No alteration of the exterior	▪ Affects the heritage values of the interior ▪ Hygrothermal conditions are altered ▪ Reduces the floor area of rooms ▪ Affects interior character and heritage values
Insulating the cavity	▪ Inserting glass fibre, cellulose fibre or foam insulation into cavities	▪ Blown-in fibre glass or cellolose fibre	▪ Non-invasive ▪ Does not affect the appearance or character	▪ Hygrothermal conditions are altered

2.5.3 Replacing windows

Windows are significantly important from an energy performance perspective. Windows both provide energy to the building and are a source of large transmission losses depending on orientation and the intensity of the solar radiation. In colder climate regions, especially when considering a longer time interval, windows are mostly a cause for heat transmission losses. The main cause of this is the thermal bridges which the window and its connection to the structure give rise to (Hilliaho, et.al, 2015). A window shielding factor (g-value) is also an important property. This parameter has a value between 0 – 1. 0 indicates that no solar radiation passes through the window, whereas, a value of 1 indicate that all radiation is let through. Windows from the past often has a g-value of 0,9, whereas, newer ones often has a value less than 0,7 (Skarning, et.al, 2016) Studies has previously shown that replacing windows to an alternative with 3-pane glazing, in Nordic climate, can reduce a buildings energy use with up to 14 % (Hilliahoa & Lahdensivu, 2015). An alternative for replacing the windows is the addition of secondary glazing. Addition of secondary glazing has been shown to reduce the total thermal transmittance with 6 % (Luciani, et.al, 2018) . Another alternative is the addition of a low emissivity layer to the original windows (Adalberth & Wahlström, 2008). A low emissivity layer reduces the energy losses by radiaiton through the window and effectively reflects it back into the building. Typical thermal transmittance of different window types is presented in table 5 (Petersson, 2009).

Table 5. U-values (W/m^{2}K) for the glas parts of windows. LE = low emissvity layer with $\varepsilon_{LE} \leq 0{,}15$, A = air, AR = argon (Petersson, 2009). p.493.

	Thermal transmittance, U_g (W/m^{2}K)					
Distance between glas panes (mm)	1 + 2 sealed windows				1+1	
	Without LE		With 1 LE		Without LE	
	1+2		1+2		1+1	1+1+1
	A	AR	A	AR	A	A
4	2,25	2,15	2,10	1,90	2,80	1,85
6	2,15	2,05	1,90	1,70	2,80	1,85
9	2,05	1,95	1,70	1,55	2,80	1,85
12	2,00	1,90	1,60	1,45	2,80	1,85
15, 20	1,95	1,85	1,50	1,35	2,80	1,85

2.5.4 Thermal bridges

The climate/building envelope separates the interior from the exterior environment. Thermal bridges arise when a conductive element passes through or bypasses the thermal barrier of the building envelope. These bridges provide a path of lesser resistance, allowing more heat to bypass the thermal resistive layers of the construction. By doing so, it affects the indoor climate by increasing of decreasing the temperatures. Examples of thermal bridges are; openings and penetrations of the construction with a low thermal resistance material, varying thickness of component parts, structural connections or when surfaces against the cold environment are maximized, such as corners (Petersson, 2009).

Thermal bridges often cause multi-dimensional thermal flux. These types of heat flow are complex to evaluate, because they depend on a wide variaties of boundary conditions. For the case-building, these have not been independently verified, and no measurement of their performance has been done. For the further analysis of the thermal bridges, and the building, standard or lower than standard values of their heat conductivity has been assumed (appendix 1). This could infact give rise to some additional uncertainty in the energy model. However, the effects can be considered to be of lesser magnitude.

3 Research methods and data collection

3.1 Data collection

Archive sources and methodology

Historical and contemporary sources have led to insights regarding the historical, social and asthethic context of the case-building. Sources include but are not limited to: bulding documentation from the LKAB Archives, statements from the Swedish National Heritage Board (Riksantikvarieämbetet), condition state of the building made by the museum of Norrbotten and a cultural envirnonment analysis conducted by Tyréns AB, the sources are listed and referred to in the body of this master's thesis. Building illustrations such as drawings, plans and sections have been gathered, information regarding permit applications, technical description and specifications of Arbetarbostäder 158 (Workers quarters 158) have also been acquired from the LKAB archive and have been used to study the original design and construction. Some construction details have been assumed to be similar to documented solutions from same period of construction (Björk, et.al, 2009), see appendix 2.

Section 2, which primarily describes the theory and theoretical framework of the conservation field, is relevant to understand and evaluate the impact of energy retrofits in heritage buildings. Furthermore, it also contextualizes the intersection between energy performance and building conservation. The method presented by the Swedish and European standard SS-EN 16883:2017 is applied to the case-building to find the balance between its conservation and its energy performance.

Input data and energy performance calculations

Energy declaration protocols (appendix 3) have been a source of some input data for the building energy simulation model. As these documents contain information of energy performance and consumption, although to a limited degree, they have been found useful for calibration and evaluation of the energy models' validity and reliability (further discussed in section 5.2). After defining a baseline performance of the case-buildings current state, proposed energy refurbishments are evaluated according to their efficiency.

SVEBY (Standardisera och verifier energiprestanda I byggnader) is a cross sectoral organization that gathers information and develops tools for the construction industry. Their publications include reports which present standardized data for calculating and verifying the energy performance of buildings. The data mostly include statistical data of stochastic variables which are of importance for the accurate energy simulation of buildings.

The software used for evaluating the energy performance of the case-building and proposed refurbishment measures is IDA ICE. This computer software provides settings and customization for a wide variety of parameters (further explanation in section 3.4).

Types of data and information

As previously alluded to, this report utilizes both quantitative and qualitative data for its finalization. Quantitave data would include; gathered statistical data, building specifics and the energy performance calculations performed in IDA ICE and by hand. Qualitative data would, in contrast, comprise of heritage value assessments in accordance to contemporary conservation principles and the standard SS-EN 16883:2017.

3.2 Case study – 'Workers quarters 158'

Figure 4. Street view of Puoitakvägen at the end of the 19th century. Source: Gällivare Bildarkiv.

The methodologies concerning energy improvement of heritage buildings that are presented in this master's thesis will be applied to a building located in the sub-arctic climate zone of northern Sweden. The specific location of this building is the mining town of Malmberget. The building itself, and as a part of a larger context, represents parts of the community's past and development. It specifically represents buildings constructed during a time-period defined as the *pioneering-stage* (*Kulturmiljöanalys malmberget,* 2017).

Original aesthetic, materials and aspects of its design can be assessed by reviewing historical photographic documentation. The case-building is the middlemost one seen in the figure 4. It was built between 1897 and 1898. Since then, the case building, also referred to as *Puoitakvägen 5* and *Workers quarters 158*, has been refurbished a number of times. The most recent and most extensive refurbishment was carried out during the 1960's.

The case building is a timber house in one and a half stories with a facade compricing of standing wood paneling. It is currently painted with a green colour. The windows mainly consist of 2-pane-glazing without mullions. There are 3 entrences from the outside and the doors are simple and incorporate windows. A frontispiece is the main feature of the backside of the building. Dormers above the entrences are part of the building's decoration. The gable roof has a finish made of black corrugated steel and its foundation is made of cut stone (Engström, 1995, p. 30).

Historical context

The abundance of iron-ore deposits in the area has been known since the early 17th century. Malmberget as a settlement was founded in 1888 as a result of the expanding rail transport network reaching the mineral deposits located in the area. Naturally, this led to increasing production. Thus, increasing demand for labour which in turn attracted people looking for work to the area. As a result, the settlement experienced significant growth and development during this era. The need for residences, working quarters, services and public utilities grew, and consequently, development of Bolagsområdet was initiated during the 1890's (Engström, 1995), p. 3).

Neighbourhood description and building tradition

The studied case-building 'Workers quarters 158' resides in the neighbourhood Hermelinen, which constitutes the westernmost part of Bolagsområdet. This neighbourhood is one of several neighbourhoods located near the iron-ore deposits. As the mining operation has expanded, larger and larger areas are susceptible to ground subsidence. Consequently, a growing number of residences have been abandoned, moved and demolished to make room for the continual expansion of the mine and its associated activities (Engström, 1995).

It is obvious that the neighbourhood was built according to a specific social hierarchy. The workers living quarters are clearly separated from the upper managerial living quarters. Most residential buildings intended for the working class are larger and have several entrences. The architectural identity of the area is defined by jugend, nationalromanticism, 20th century classism and functionalism. The neighbourhood Hermelinen is architecturally typical for settlements from the same era. It was during the time between 1890-1900 that most of the worker quarters were built in Hermelinen. These accommodations were simple and sparsely decorated. Common for nearly all buildings from this era is the gable roof construction with brake-formed steel finish (Engström, 1995, p. 5-8).

Figure 5. 'Workers quarters 158' (encircled building) and surrounding neighbourhood.
Image provided by Google Maps (2018).

Refurbishment of the 1960's

During the 1960's the building was refurbished. Alterations were made to existing walls. The original outside paneling was replaced by a thermal insulation layer, an air gap with vertical studs and new paneling (appendix 4). The external finish is at the present state remarkably different from what we can observe from pictures and other historical documentation (pictures from Gällivare Bildarkiv). The interior of the exterior walls has also been tampered with, wood fibre boards and additional paneling and/or finishes were added during the refurbishment measures of the 1960's. Interior surfaces have also been altered, for example, most of the floors have had their finish changed to one made of linoleum. The livingroom floor finishes have been replaced with parquet floors. The small roof windows clearly visible on earlier drawings (appendix 5) have been removed, most likely due to their limited function, since those spaces were primarily used for storage.

Heritage significance and character defining elements

Figure 6. Parts of Malmberget and adjacent environment at the end of the 19th century. Source: Gällivare Bildarkiv.

According to a cultural environment analysis of the community (*Kulturmiljöanalys Malmberget, 2017)* the heritage significance of the building mainly resides within the social and historical context of the building. This assessment is partly based the declaration of national interest made by the Swedish National Heritage Board (Riksantikvarieämbetet, 1997): *"Motivation: Two mining communities (Malmberget and Koskullskulle) with associated characteristic and time-period defining structures that reflect economical conditions and social stratification from different stages of development. Expression of national interest: Communities with characteristically divided housing; the corporate area (Bolagsområdet) and individual built-up areas. The corporate areas are at present time relatively intact, with labour, service and managerial housing…"*. Figure 6 captures the ambience of the neighbourhood's past.

Particual for this specific neighbourhood is the size of the lots. Here, they are smaller and more densly built than in other similar neighbourhoods (Engström, 1995, p. 5). The buildings also reflect the interest of LKAB in the production and management of the workers quarters at the era refered to as the pioneering-stage which extends to the year 1900. The building itself have some character defining elements worthy of preservation. These have been defined according to the report *Kulturmiljöanalys Malmberget (2017)* as: ***the volume of the building, the shape of the roof (including details), fascades and their paneling, window shape and placement, entrencés and balconies, smokestacks and their materials and the granite foundation***.

Assessment of the use of the building

Currently the building is situated at Puoitakvägen 5 in Malmberget, Sweden (figure 7). It's occupied by multiple households, since it's a multi-dwelling block consisting of 4 separate apartments, two on each floor of the building. A decision has been made by the municipality and LKAB to move the building to a new location. It will be relocated to a newly developed part of Koskullskulle, a few kilometers from the current location. The building will be moved together with a few other houses that have been deemed worthyof preservation, especially as a coherent group of buildings.

Figure 7. Current state of 'Worker's quarter's 158'. Photo: Norrbottens Museum (Report 2009:22).

Conditions after relocation and current maintenance

The placement of the buildings after relocation should try to emulate the conditions of the original site according to the value assessment. The density and building lot should be of identical size and shape. The building's orientation should also be considered important. The exterior and associated details should be preserved (Kulturmiljöanalys Malmberget, 2017). External parts which are demolished or detatched during the relocation should be recreated (*Kulturmiljöanalys Malmberget,* 2017, p. 41). The basement, however, will not be recreated at the new site. A crawl-space will be constructed instead. No definitive structural plans or drawings have been found. The crawl-space will possibly be constructed as a bricktype wall with external XPS insulation with a concrete floor also insulated with XPS boards. This was the solution used for another building when it was moved to the new site.

Construction elements of the building envelope

Table 6 below lists essential and basic information regarding the case study building. Structural elements, subcomponents and thickness are listed in accordance to the information provided in the technical description of the building (appendix 4). The U-values (W/m^2K) have been calculated directly from the computer-generated building energy model.

Table 6. Construction and thermal performance of building elements constituting the building envelope.

Construction element	*Number of layers/subcomponents Description*	*U-value (W/m^2K)*	*Approximate thickness and comments*
Attic roof	1. Steel finish 2. Air infiltration barrier 3. 25 mm wood paneling 4. 175x75 mm beams c/c 600 mm	3.12	200 mm, not including the steel finish. Modeled as ventilated steel roof.
Roof (stairwell and heated spaces)	1. Steel finish 2. Air infiltration barrier 3. 25 mm wood paneling 4. 175x75 mm beams c/c 600 mm filled with sawdust insulation 5. 70 mm mineral wool and studs 6. 25 mm wood paneling 7. 6 mm wood fiber board	0.31	225 mm, not including the steel finish. The cavity in-between the beams has been assumed to be filled with sawdust insulation. Information presented in appendix 1 and appendix 6 support this assumption.
Attic floor	1. 225x75 mm beams c/c 600 mm filled with sawdust insulation 2. Air infiltration barrier 3. 25 mm paneling (sub-floor) 4. 50 mm studs and 25 mm mineral wool 5. 25 mm paneling/wood fibre board	0.30	325 mm.
Exterior wall	1. 30 mm paneling 2. 25 mm air gap and vertical studs 3. 50 mm mineral wool and studs 4. 75 mm plank (timber) 5. Air infiltration barrier 6. 50 mm air gap and studs 7. 19 mm wood paneling fibre board 8. 6 mm wood fiber board	0.37	255 mm.
Bottom floor	1. 25 mm paneling 2. Air infiltration barrier 3. 225x75 mm beams c/c 600 mm filled with sawdust insulation 4. 25 mm paneling	0.37	275 mm not considering the floor finish. Also see appendix 7
Basement floor	1. 180 mm concrete (estimation)	3.63	180 mm (not verified).
Basement walls	1. 500 mm granite (approximation) 2. 50 mm internal wood wool board	1.08	550 mm, estimation based on basement floor plan.
Entrence door	Non-insulating entrence door	2.20	Number of doors and their area are listed in appendix 8.
Windows	2-pane-glazing	2.70	-

3.3 Limitations

This section of the master's thesis will discuss the application of the methodology described by the standard SS-EN 16883:2017 to the case-building. Some limitations have been implemented in an effort to reduce the scope of the project, others are imposed in order to reduce the complexity of the project and the need for multi-disciplinary expertise.

The guidelines propose several assessment categories to consider. Nevertheless, a number of assessment categories and assessment criterias have been excluded. These are the categories and criterias which are not directly related to the heritage significance of the building and its settings and energy. Some categories are partially considered, one of which would be technical compatibility. For example, the hygrothermal properties has only been partially addressed by excluding non-breathable materials from consideration. No hygrothermal analysis for the proposed refurbishment measures has been conducted, as this would extend beyond the scope of this master's thesis. The reversibility of the refurbishment measures has been considered, which also falls under the category of technical compatibility. Economic viability, indoor envorinmental quality and impact on the outdoor environment have been excluded entirely.

Table 7 below lists all categories and criteria considered within the scope of this master's thesis. The proposed refurbishment measures will be assessed using a five-level scale (SS-EN 16883:2017, p. 22). The overall assessment however is modified to reflect the limitations previously discussed.

Table 7. Assessment categories and criteras in accordance with SS-EN 16883:2017.

Assessment category	***Assessment critera***
Technical compatibility	Hygrothermal risks (slightly considered)
	Reversibility
Heritage significance of the building and its settings	Risk of material, constructional, structural impact
	Risk of architectural, aesthetic, visual impact
	Risk of spatial impact
Energy	Energy performance and operational energy demand in terms of primary energy rating (total)

Building survey

The building survey and assessment provides the necessary information about the building in order to make an informed decision on any energy performance improvement measures. The building survey includes, but are not limited to; general information, describing heritage significance and conservation opportunities, assessment of the current use, documenting the structural type and elements, energy performance assessment. The building survey has in fact been performed in section 3.1 and 3.2. The energy performance assessment is, however, presented in section 4.2.1.

Construction and estimation of compositions

Björk et. al. (2009) have observed and documented common building techniques used in Sweden during the last few centuries. By comparing the case building to what has been documented by Björk et. al. (2009) made it possible to obtain necessary input for establishing a reliable representation of the construction elements. This method of approximating the composition of the building elements was necessary in two different cases; (1) when drawings and other documentation were lacking essential information in combination with the absence of invasive and destructive analysis, (2) during the assessment of some building elements (and their compositions) as they would have been before the 1960's refurbishment. Furthermore, the building has since its construction experienced what can only be assumed to be several refurbishments, which means that the building has been altered numerous times.

Dimensions of the basement walls have been approximated by studying rudimentary basement floor plans where no actual measurements were given (appendix 9), this of course, leads to the deviation from actual conditions and introduces uncertainties into the evaluation of the energy performance. The basement wall has been verified to be made granite (appendix 4), which is one of the most common natural stones utilized for foundational structures from the same time period (Björk et al., 2009). As Björk et al. (2009) further explains, the foundational wall was often driven down approximately two meters below the ground level, as to form a basement, which is the case for *'Worker's Quarters 158'*.

Another prominent source of information is an energy declaration protocol from 2008 (appendix 3). This protocol directly refers to Puoitakvägen 5, but also to one of its neighbouring buildings, Puoitakvägen 3. It is stated in the protocol that both buildings have similar construction characteristics and composition. Since these two buildings essentially are the same, aspects of the construction and composition of one of them has been assumed to be identical for the other. Therefore, some limited documentation regarding Puoitakvägen 3 has also been taken into consideration when determining the construction, characteristic and features and composition of Puoitakvägen 5.

During a site visit, the external wall was confirmed, by simple measurements, to be approximately 250 mm. A more extensive inspection was not performed due to the building being occupied by residents at the time of visitation. A more extensive visual inspection could have provided some additional information, which could make a few of the assessments less based on inadequate documentation and the uncertain nature of historical sources.

The roof has been modeled by assuming specific characteristics of the air in direct contact with the roof itself. These types of air layers can be simplified by using standard values. Since the roof is self-ventilated and the finish is made from steel, the air layer and the external finish can be assumed to have a combined thermal resistance of 0,15 m^2K/W ((Petersson, 2009). The external surface thermal resistance is not included in this value.

The U-value of the external wall has been independently corroborated by the energy declaration protocol (appendix 3). The protocol estimates the U-value of the external wall to be 0,4 W/m^2K. Which can be considered close to the calculated value of 0,37 W/m^2K. There are however additional data regarding the U-value of the external wall which do not corroborate a value of approximately 0.4 W/m^2K. This single measurement suggests that the external wall has a U-value of 0,32 W/m^2K. These results further weaken the reliability of the model. However, two independent sources have approximated the U-value of the external wall to be roughly 0,4 W/m^2K. The newly measured value could in fact be misleading and be a result of, for example, variations within the external wall.

3.4 IDA Indoor Climate and Energy (IDA ICE) – Building energy model

IDA Indoor Climate and Energy (IDA ICE) is a dynamic multi-zone simulation application for the accurate study of the thermal indoor climate of individual zones as well as the energy consumption of an entire building. IDA ICE has been validated with respect to CEN Standards EN 15255-2007 and EN 15265. Furthermore, it has received several other certifications from institutions and industry experts (International Energy Agency SHC Task 34, Techincal Memorandum 33, LEED and BREEAM, DGNB). The software provides settings and customization for the following parameters: shading, building elements, location, weather, mechanical ventilation, infiltration, thermal bridges, ground properties, and system distribution losses. After an energy load simulation ICA ICE produces a variety of data including, but not limited to heat supplied, window heat losses, building-envelope heat losses and ventilation heat losses,

IDA ICE Workflow and progression chart

The workflow and process of modelling the building in IDA ICE is described in table 8 below. Its's a general workflow chart for completing an accurate and representative energy model of the building.

Table 8. Stages of modelling and producing simulation reports in IDA ICE.

Modelling stage/progression	*Description/comment*
1. Building geometry and CAD	Imported to IDA ICE from SketchUp Pro 2017
2. Define default constructions	Common construction elements and their material layers are defined. Other elements are defined separately.
3. Inserting zones	Zones (rooms) are defined within the external building body.
4. Windows, doors and internal openings	In two adjacent zones, there is a possibility to modify openings, position and size.
5. Site shading and orientation	Orientation of the building.
6. Location and weather	Weather files are imported from the database.
7. Ventilation system	Adjustment of the ventilation system and components.
8. Infiltration	The air leakage is defined.
9. Thermal bridges	The quality of thermal bridges is defined by heat conductivity per meter joint. See appendix 1.
10. Ground properties	Ground model is chosen.
11. System distribution losses	Energy distribution method. See appendix 4.
12. Heating load calculation and results	All defined input data are considered when calculating the heating load. Results of the simulation can be interpreted.

IDA ICE Base model

No original drawings of the building from 1898 have been discovered during the research phase of the project. The energy model is primarily based on drawings and documentation from the 1960's (appendix 4, 5, 9 and 10). However, these drawings and accompanying documentation were somewhat limited in their comprehensiveness. For instance, no precise dimensions were visible on the physical drawings. The models' size and geometry are based on scanned drawings from the 1960's. This introduces some uncertainty in the accuracy of the model, however, the difference between the actual area and the model area will be considered negligible. Furthermore, IDA ICE presents additional area options for inclusion in energy performance reports. All energy performance reports (presented in section 4.2) are based on an area of 432 m^2, which is the same as the buildings' actual area (A_{temp}), see appendix 6.

The building was modelled in IDA ICE by importing external building geometry from the 3D modelling software SketchUp Pro 2017, see figure 8. The building body represents, in this case, the inside of the building envelope and its building elements. The figure can also be thought of as to represent the volume of the building restricted by its internal surfaces.

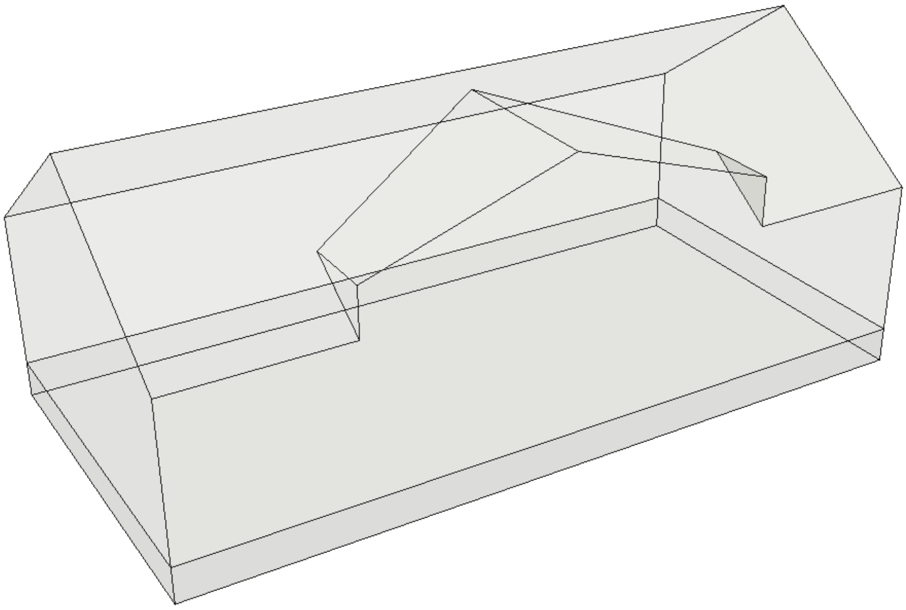


Figure 8. Imported external building body and geometry as displayed by IDA ICE. The building has been modelled with a crawl-space instead of a basement in this figure. This figure does not represent all considered scenarios.

Zone/room boundaries are presented in appendix 11. The model consists of 46 different zones. Most of them have the same settings, which means they have similar heating equipment, temperature set-points, ventilation flow, etc. Settings differ for the attic and the basement, since these spaces are not heated to more than 10 °C (appendix 12), and therefore, do not account for additional temperature-controlled spaces (A_{temp}).

IDA ICE - Base model, settings, climate data and other considerations

Input data, sources, settings and considerations are listed in table 9. The input data represent the current, or in other words, the "base case" of the building. The building energy model of the base case represents next to all present state internal and external factors, ranging from existing design and construction to a wide variety of environmental factors. User affected parameters have previously been presented in section 2.6.1. Input data has been gathered from a variety of sources, including the energy declaration protocol, SVEBY, BBR, Statistics Sweden (SCB) and the technical description of the building.

In the municipality of Gällivare, in residences with similar apartments sizes and form of housing, the average number of occupts is 6.2 (SCB, 2018). This has been taken into account, in the energy model by distributing 6.2 occupants among all bedrooms and kitchens throughout the building. The occupants have been assigned a presence schedule which dictates during which hours of the day that they are inside the building. The occupants are present from 5 am to 8 pm during weekdays and around the clock during weekends.

The building is located in a suburban neighborhood, for the energy model this is of relevance when wind exposure and wind profile are to be chosen. A standard IDA ICE wind profile has been chosen for suburban neighbourhoods.

Climate data is an essential input for any building energy simulation. ASHRAE provides what they describe as "typical year" weather files. One such weather file has been imported into the IDA ICE model. Although, no climate data for Malmberget was available. This led to a climate file for Kiruna to be chosen instead. Both Kiruna and Gällivare (including Malmberget) have been assigned a similar geographical adjustment factor, see section 2.3.2. This factor indicates, since both Gällivare and Kiruna share the same value, that both locations have comparable climate conditions. Some variations from actual conditions, especially local weather conditions, will be introduced into the energy model as a result of choosing a climate file which represents another location. However, regional climate differences can, for the sake of further analysis, be considered negligible.

Energy consumption data for property and household electricity have been gathered from an energy declaration protocol for the district in which the case-building is located. According to the protocol residential dwellings constitute 93 % of the total building stock of the district. The other 7 % includes other types of buildings (appendix 3). The energy declaration protocol also contains information regarding construction elements, U-values, energy distribution system and heatead indoor floor area.

Some U-values for composite material layers have been calculated manually (appendix 13). These simplifications have been made in an effort to reduce the complexity of defining material dimensions and parameters within the building energy model.

The values of the thermal bridges have been set to the preset value "typical" as defined by IDA ICE. The specific values depending on the structural connection of the thermal bridge is presented in appendix 1.

Table 9. Input data and settings for the building energy model.

PARAMETER CATEGORY	SUB-CATEGORY	EXPLANATION	VALUE/ SETTING	SOURCE/ COMMENT
Geographic information	Location	Coordinates	67.817 N, 20.333 E	Approximation
	Climate data file	Temperature, atmospheric pressure, wind speed etc.	SWE_KIRUNA_ 020440_IW2.PRN	ASHRAE IWEC2 Weather File for KIRUNA
	Orientation	Rotation of locally defined coordinates	189.1°	Approximation
	Wind profile	Suburban	Semi-exposed	ASHRAE 1993
Indoor temperature	Zone temperature	Controller set-points for individual zones	Min 21 °C Max 25 °C	SVEBY (2012)
Windows	Properties	Factors	g = 0.76 T = 0.7 T_{vis} = 0.81	IDA ICE standard setting
Domestic hot water (E_{tvv})	Heating energy	Yearly consumption	37 kWh/A_{temp}(m^2), 15 984 kWh	Energiprotokoll för Fastighet: Malmberget 8:17#Puoitakv-Krokv
	Internal gains	Internal gains from domestic hot water	20 %	SVEBY (2012)
Tenant electricity (E_t)	Energy consumption	Yearly consumption	29,4 kWh/A_{temp}(m^2)	30 kWh/A_{temp}(m^2) according to the energy declaration protocol (appendix 3)
	Internal gains	Internal gains from electric devices	70 %	SVEBY (2012) & Petersson (2009)
Facility electricity (E_f)	Energy consumption	Yearly consumption	14,6 kWh/A_{temp}(m^2)	14,0 kWh/A_{temp}(m^2) according to the energy declaration protocol (appendix 3)
Occupants	Number of people	Number of people for similar dwellings	6,2	Statistics from SCB (appendix 14)
	Attendence	Presence schedule	Weekdays: 17-08 Weekends: 24-00	SVEBY (2012)
	Effect	Energy in joules per second	80 W (J/s) (MET 0.8)	SVEBY (2012) & Petersson (2009)
	Internal gains	Internal gains from people	100 %	SVEBY (2012)
Heat losses	Thermal bridges	Quality	Typical	Appendix 1 (Standard IDA ICE Settings)
	Infiltration	Property of older buildings	0,5 l/s A_{om} (m^2)	Slighly adjusted standard value
	Ground model	Standard	ISO-13370	Global standard
	Building envelope	Construction and U-values	According to table 6.	Appendix 4 and appendix 6
Ventilation (losses and equipment)	On-demand airflow	Kitchen fan	No forcing of the fan	SVEBY (2012)
	Additional ventilation losses	Additional energy consumption	4 kWh/A_{temp}(m^2)	SVEBY (2012)
	Return air only (no supply side)	Natural ventilation. Air flow in rooms	Min 0,35 l/s m^2 Max 0,35 l/s m^2	Minimal air-flow according to BBR
Energy system	District heating and cooling	Energy supplied to for heating	No distribution losses	No technical information on the district heating system
	Internal energy distribution system	Number of water radiators	38	Technical description

IDA ICE Energy balance

In section 2.3, the energy balance of buildings in general is presented. Figure 9 below is a modified version of figure 3. The energy carriers are district heating and electricity, no fuels are used for heating needs. The quantity of delivered electricity to the building can be divided into tenant electricity (E_t) and facility electricity (E_f). Energy meters for equipment and light fixtures within the energy model are chose to reflect this. What constitutes tenant and facility electricity has already been presented, see section 2.4. SVEBYs definitions corresponds to BBRs definitions. This will allow the building performance to be properly evaluated, in accordance to the building regulations. The heating of domestic hot water is according to the energy declaration (appendix 3), 37 kWh/A_{temp} and year. This value has been used instead of the standard value (25 kWh/A_{temp} and year) for multi-family dwellings which SVEBY recommends when no other data is available.

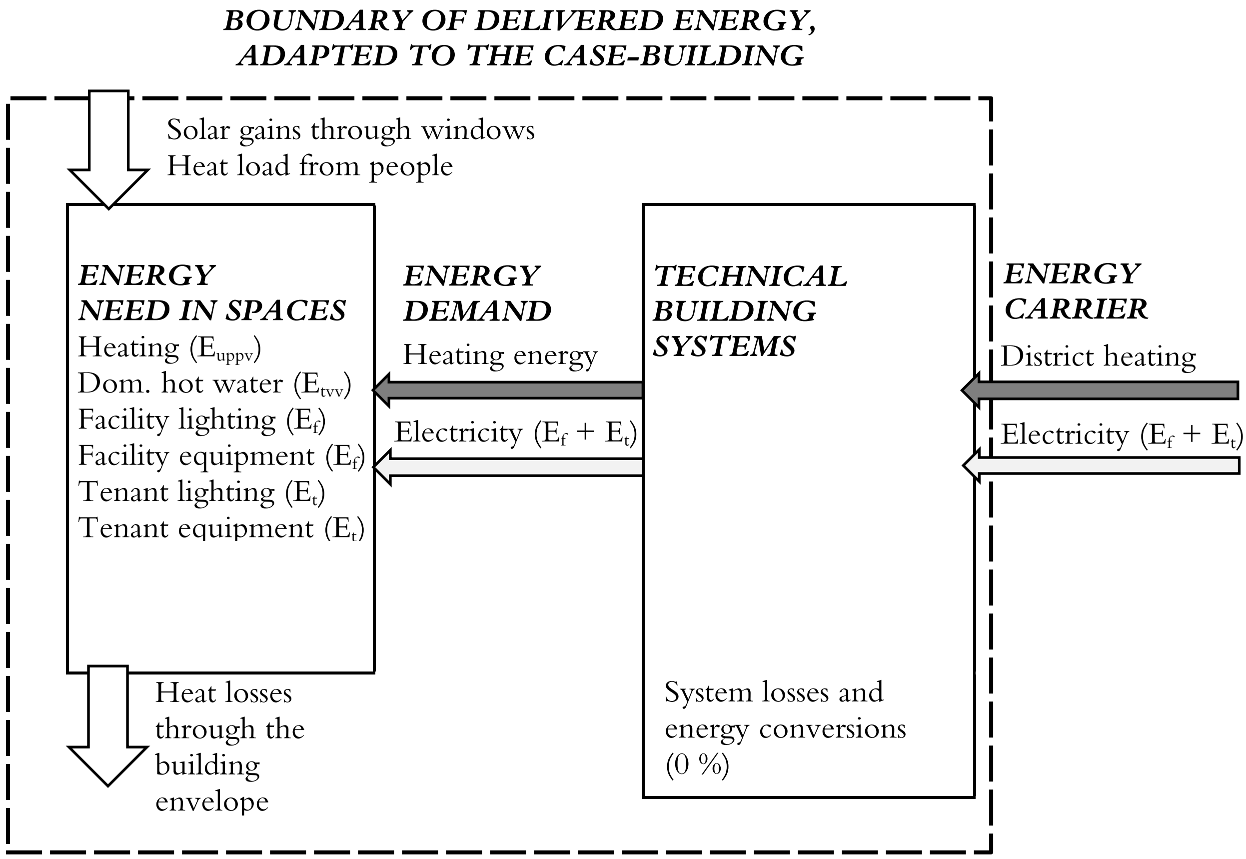


Figure 9. Boundary of delivered energy. Modified to reflect the energy carriers and heating systems of Puoitakvägen 5. The electricity is also divided into tenant and facility electricity for evaluation in accordance to BBR.

3.5 *Energy performance reports*

IDA ICE energy performance reports are the basis for the evaluation. The reports include information on delivered energy, which is divided into categories. The categories include district heating (space heating and heating of domestic hot water), tenant and facility lighting, tenant and facility equipment etc. Some of these posts are dependent on probabilistic, stochastic and dynamic factors. Some of them are directly correlated to the climate.

4 Results

4.1 Assessment and selection of measures for improving energy performance

The suitability of materials and their properties are presented in section 2.5. In table 10 below, an assessment of the refurbishment measures is made by taking their impact on heritage values into account.

The assessment of the impact on heritage significance impact in this master's thesis will be based on the criteria mentioned in table 7. The acceptability of the refurbishment measures is measured the following scale: completely acceptable, very acceptable, moderately acceptable, slightly acceptable and not acceptable. This assessment scale is different from the one proposed in the standard SS-EN 16883:2017. The applied scale evaluates impact on the heritage values only and is thus different from the scale suggested by the standard.

Assessment and categorization of proposed refurbishment measures

Section 3.2 of this master's thesis mentions the statement of significance, heritage significance and character defining elements of the case-building as defined by the Swedish Heritage Board and the cultural environment analysis (*Kulturmiljöanalys Malmberget,* 2017). The proposed refurbishment measures will be categorized in accordance to their impact and intrusiveness on the character defining elements. The assessment also takes the principles of conservation into consideration, which were introduced in the theoretical framework (section 2).

Completely acceptable refurbishment measures

Measures which concern the replacement of cavity-fill insulation (replacement of the sawdust-fill insulation) have all been categorized as measures with no significant impact on design, visual and/or spatial values. Primarily since they do not make changes to the listed characted defining elements. Thus, do not affect the authenticity of the building in any considerable manner. These measures can also be considered, at least to a certain degree, reversible.

Measures concerning the refurbishment and changes to the basement have also been categorized into ones which are completely acceptable due to similar reasoning (as the case concerning cavity-fill insulation). Due to the fact that the building will get, as previously mentioned, a new structural foundation. Further changes to the structural foundation have been categorized as completely acceptable.

Very acceptable refurbishment measures

Refurbishment measures which affect the attic has been categorized as having little or no impact on the heritage values. Mostly, due to the fact that no character defining element is being affected by additional insulation of the attic floor. Moreover, these measures do not affect the external appearance of the building.

Measure L proposes making changes to the windows. The windows have, as mentioned in section 3.2, been listed as of the building's character defining element. This particular measure proposes the addition of an additional pane of glazing. This pane of glazing would be added to the internal side of the window and would as a result not affect the building's external appearance. This measure can also be argued to be somewhat reversible since it has minimal impact on the appearance of the original windows. It is also relevant to point out that the characteristics which should be preserved (mentioned in section 3.2) are tied to the placement and the shape of the windows rather than their historical or material authenticity.

Refurbishment measures which affect the internal side of the exterior wall is also categorized as very acceptable due to them only affecting room proportions and not any of the expressed character defning elements. Affecting room proportions would be classified as having a spatial impact according to SS:EN 16883:2017. However, refurbishment measures with spatial impact that do not affect any expressed character defining element will not be considered to impact the heritage values of the building.

Moderately acceptable measures

Measure M proposes the replacement of the external windows with high performance ones. This measure can be considered as moderately affecting the expressed characted defining elements because the characteristics that should be preserved are mostly tied to the placement and the shape of the windows, as previously stated. This might allow the windows to be changed into high performance ones if both original placement and shape are preserved.

Slightly acceptable measures

This category is assigned to measures affecting the external appearance of the building. Since some of the combined heritage value of the case-building is tied to the external appearance, changes to it may only be slightly acceptable. The refurbishment measures concerning additional insulation of the facade affect visual and material aspects and thus affects the authenticity of the building. The only reason why these measures are not considered completely unacceptable stems from the fact that the building already experienced major refurbishment during the 1960's. During this refurbishment, the construction of the external wall was heavily altered.

Table 10. Impact assessment of refurbishment measures on heritage values.

Building element	***Reference***	***Description of proposed refurbishment measure***	***Impact of refurbishment measure on heritage value***	***Comment***	***Acceptability of refurbishment measure***
Attic floor	***A***	Replace the sawdust-fill insulation between the rafters with cellulose fiber (loose-fill)	Material, structural	Low material values, minimal impact, reversible	completely acceptable
	B	Replace the sawdust-fill insulation between the rafters with blow-in fibre glass	Material, structural,	Minimal impact, Reversible	completely acceptable
	C	Additional attic floor insulation (glass-fibre), 300 mm	Material, structural, visual	Only affects the the attic	very acceptable
	D	Additional attic floor insulation (glass-fibre), 500 mm	Material, constructional, visual	Only affects the the attic	very acceptable
Exterior wall (externally)	***E(1)***	Addition of wood fibre board 50 mm	Material, structural Visual (architectural and aesthetic)	Affects a character defining element	slightly acceptable
	E(2)	Addition of wood fibre board 80 mm	Material, structural Visual (architectural and aesthetic)	Affects a character defining element	slightly acceptable
	F	Additional mineral wool insulation 50 mm	Material, structural Visual (architectural and aesthetic)	Affects a character defining element	slightly acceptable
	G	Addition of aerogel insulation panels 25 mm	Material, structural Visual (architectural and aesthetic)	Affects a character defining element	slightly acceptable

Exterior wall (internally)	***H***	Replace 6 mm wood fibre board with a 50 mm wood fibre board	Material, visual (aesthetic), spatial	Affects internal aesthetics	very acceptable
	I	Addition of EPS board 50 mm	Material, visual (architectural and aesthetic), spatial	Affects internal aesthetics	very acceptable
	J	Addition of PUR board 50 mm	Material, visual (architectural and aesthetic), spatial	Affects internal aesthetics	very acceptable
	K	Addition of cellulose insulation panels 50 mm	Material, visual (architectural and aesthetic), spatial	Affects internal aesthetics	very acceptable
Windows	***L***	Additional glazing (3-pane glazing, from 2) U = 1,3 W/m^2K	Visual, material	Slight visual change, reversible	very acceptable
	M	High performance windows U = 0,6 W/m^2K	Visual, material, constructional, architectural, aesthetic	Moderate visual change (The change does not affect form or placement)	moderately acceptable
Bottom floor	***N***	Replace the sawdust-fill insulation between the rafters with cellulose fiber	Material, structural	Low material values, minimal impact, reversible	completely acceptable
	O	Replace the sawdust-fill insulation between the rafters with blow-in fibre glass	Material, structural	Low material values, minimal impact, reversible	completely acceptable
Structural foundation	***P***	The old basement will not be reconstructed. A crawl-space will be built instead, with the addition of XPS boards.	Visual, material, structural	Necessary change (therefore, assessed as completely acceptable)	completely acceptable
Roof (in contact with heated spaces)	***Q***	Additional mineral wool insulation board 50 mm	Visual, material	Limited visual impact	very acceptable
Doors	***R***	Replacement of exterior doors (U = 1,2 W/m^2K from 2,5 W/m^2K)	Material, visual (aesthetics)	Not assessed as character defining	moderately acceptable

Only materials which display water vapour permeable properties have been selected for the proposed refurbishment measures, these include most common insulation materials, such as glass fibre, cellulose and wood fibre. EPS boards are considered for some measures, since they also are considered a rather breathable material. Advanced insulation materials such as PIR, PUR and XPS which display insignificant water vapour permability (table 3) have been deemed not worthy of consideration, since they would significantly increase the risk for moisture, frost and mould damage inside the construction. There is one exception, which is the use of XPS boards as insulation in the new structural foundation (corresponds to the scenario were the building has been moved to its new location and a new foundation has been built).

Changes to the foundation/basement will be considered to not further affect the heritage value in any significant way since the changes to the foundation will occur as a result of the building being moved to the new location. The building will get a crawl-space instead of a basement. Since this part of the building will undergo major structural, functional and aesthetic changes, further intervention can be argued to have little or no effect on the remaining heritage value this part of the structure holds.

4.2 *Results of energy performance simulations*

The buildings energy performance (E_{bea}) is evaluated by applying equation 1 (section 2.3.2) to the outcome of all individual refurbishment measures and all scenarios (table 11 and table 12). Evaluation of the effectiveness of each individual measure and the proposed packages of measures is made by comparing the simulation outcome to the base line of the building.

4.2.1 *Case study building – Base line*

The base model represents the current state of the building. This state is modeled on drawings and associated documentation from the 1960's refurbishment. Table 6 and table 9 define all relevant input data for the baseline condition of the building's energy performance. When other refurbishment measures or alterations are evaluated, their efficiency will be compared to the base line value. The base line performance is presented in figure 10 as well as in figure 11. Additional information can be found in appendix 15.

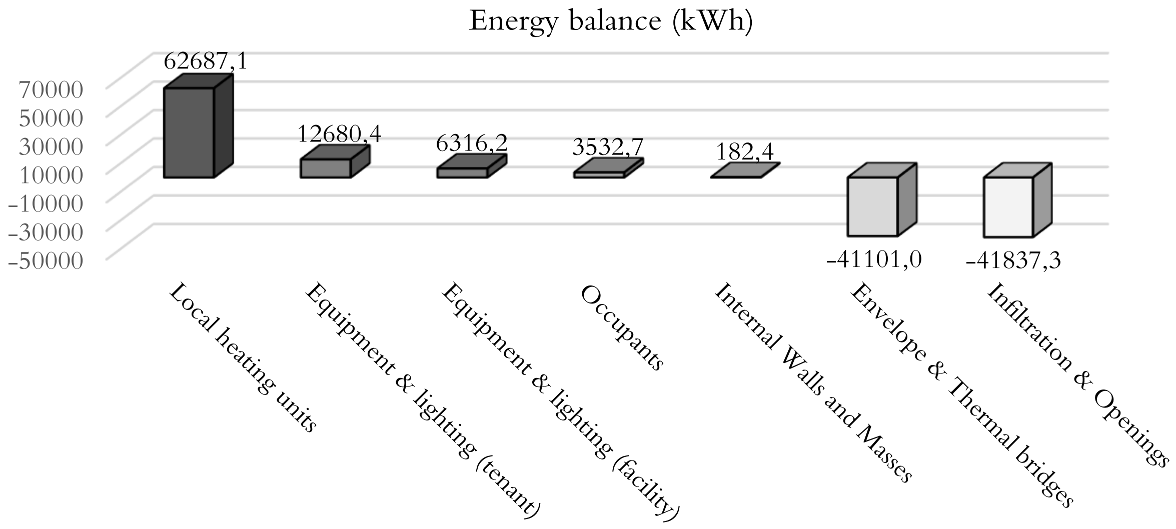


Figure 10. The energy balance of the building when no refurbishment measures have been implemented.

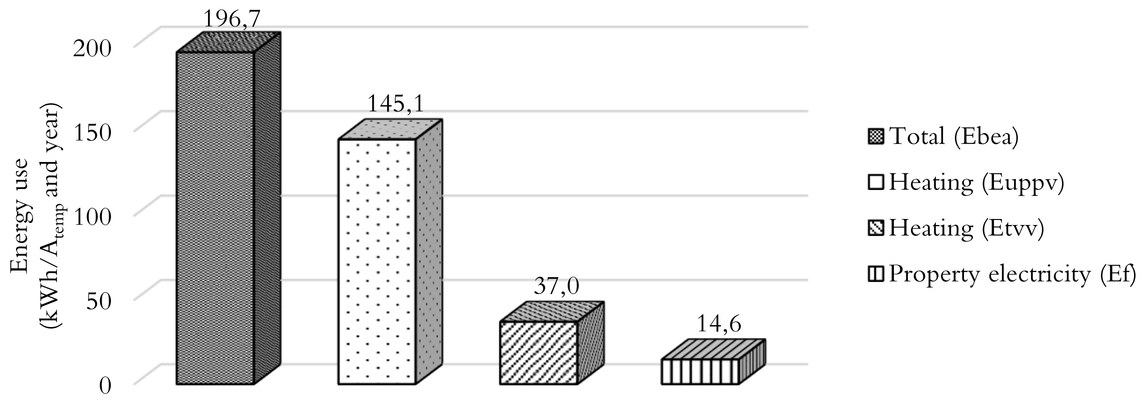


Figure 11. Energy performance of the building with no implemented refurbishment measures expressed as its energy use divided by the area in contact with heated indoor air (kWh/A_{temp} and year).

The energy declaration protocol claims that the heat requirement reaches 137 kWh/m^2(A_{temp}) and year (appendix 3). According to the simulation, the energy required is 145,1 kWh/m^2(A_{temp}) and year, see figure 11. The primary energy value (EP_{pet}) is calculated according to equation 3. The heating energy for spaces (E_{uppv}) is adjusted by a geographical adjustment factor of 1,9 (see section 2.3.2). After adjustments for location and energy carrier the primary energy value is calculated to 113,4 kWh/m^2. Which is 33,4 % higher than the current requirement expressed by Boverkets Building Regulations (BBR), see table 1.

The difference between the heating energy according to the energy declaration and the simulated result is 5,6 %. The difference can probably be attributed to temperature variations, uncertainty of the composition of some construction elements and the assumption regarding the air-tightness of the construction. However, the fact that the difference is only 5,6 % indicates that the assumptions regarding the air-infiltration rate is, at the very least, close to the actual rate.

The simulated energy performance of the building only deviates 0,9 % from the heating energy use according to the energy declaration, this is well within acceptable margins of error (Elmroth, 2015). This provides a firm basis for the evaluation and comparison of the proposed refurbishment measures.

4.2.2 Energy performance evaluation of the refurbishment of the 1960's

During the refurbishment of the 1960's some energy improvement measures and renovations were implemented. These measures affected both internal and external characteristics and consequently the thermal properties of the building. These refurbishment measures included; (1) a 50 mm batt of mineral wool insulation to the external wall, (2) a 70 mm mineral wool batt and stud construction to the inside of the roof (specifically to the roof above the stairwell and other heated spaces), (3) a 50 mm wood wool board to the interior of the basement wall, (4) a 25 mm mineral wool board to the attic floor, (5) a 50 mm wood wool board to the basement wall, (6) wood fibre boards attached to some wall and floor surfaces. Wood wool- and wood fibre boards can be assumed to have been later additions, and not part of the original structure.

The effectiveness and the contribution of these refurbishment measures are evaluated by modifying the base model, see figure 12. In the model, the material layers mentioned above are removed. No other variables are being changed in order to establish a rough estimation of how the energy performance of the building was changed after the refurbishment.

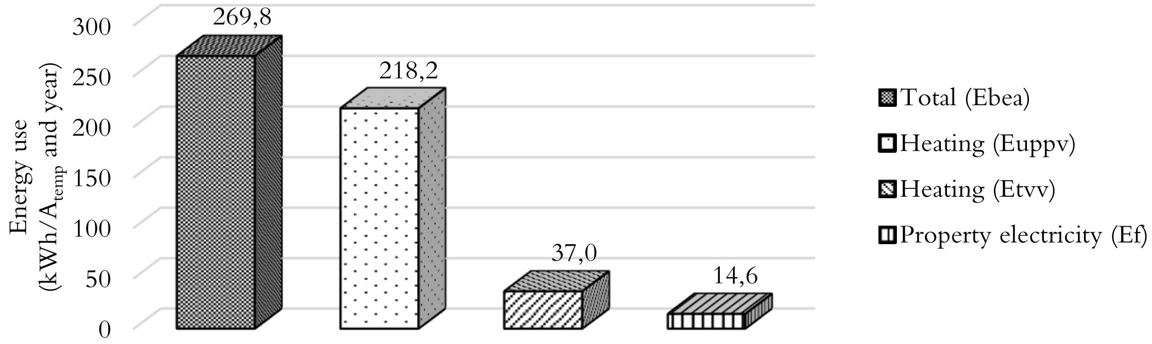


Figure 12. The building's energy use as it would have been without the 1960's refurbishment, assuming no other factors or variables are changed. This assumes equivalent air infiltration rates and energy consumption.

The building's energy use (E_{bea}) is 37,2 % less effective in comparison to the base line performance (table 11). This result assumes no changes to the energy consumption and air infiltration rate etc. These factors have not been changed for purposes of making relevant comparisons and evaluations. Although, the refurbishment measures of the 1960's probably resulted in a construction with a lower air infiltration rate.

The total number, placement and window sizes were also changed during the actual refurbishment. However, proper documentation regarding the details of what has been modified is unavailable. The energy performance of the windows has been lowered in this simulation, no changes have been made to neither the geometry of the basemodel or window placement and area. And therefore, does this simulation only approximate the contributions of the windows.

4.2.3 Foundational structure changed from a basement to a crawl-space

Within the foreseeable future the building is going to be moved from its current location, after the relocation the building will be placed on a different foundational structure. This change will affect the volume of the space beneath the liveable area, and therefore, affect the energy performance of the building. However, since neither foundational structure is part of any temperature-controlled spaces, which are intended to be heated to more than 10 °C (A_{temp}), the effect on the energy performance of the building is of lower magnitude. One factor which affect the energy performance more significantly is the removal of the electric equipment (laundry machies etc) in the basement. After the relocation, none of these electric appliances will contribute to the building's property electricity (E_f). Figure 13 shows the effects of these changes. No information on how this specific building's foundation will be changed was available. However, similar buildings have already been moved and their basements have been replaced by crawl-spaces. According to the information gathered, these crawl-slaces were designed with an enclosing brick wall (~300 mm) with an external 100 mm XPS insulation board. The ground is covered by a 180 mm concrete slab with two layers of external XPS insulation, which have a combined thickness of 150 mm. The case-building will, for the sake of further analysis, be assumed to receive a comparable foundational structure.

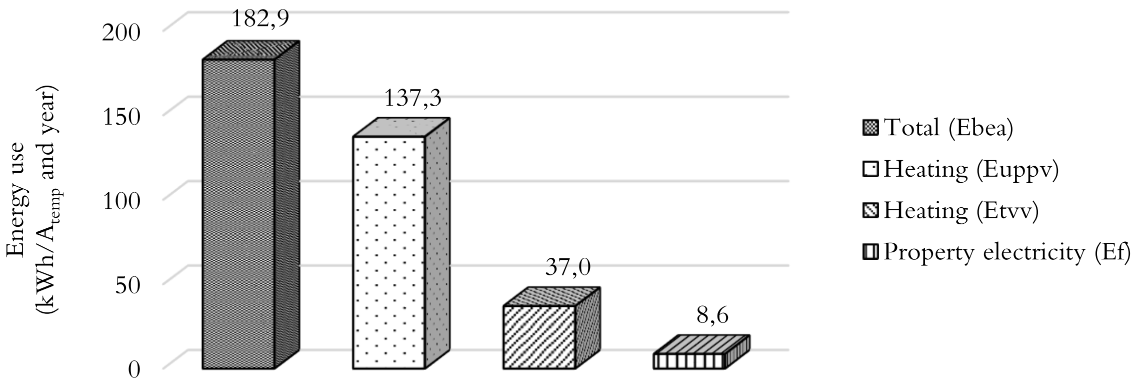


Figure 13. The building's energy use after it has been relocated.

The heating energy use (E_{uppv}) is reduced by 5,4 % (table 11) after changing the structural foundation to a crawl-space. Limited change is expected since the basement of the current version of the building is not heated and consequently, the heated area (A_{temp}) of the building is not reduced. Moreover, the insulation of the bottom floor already forms the barrier between the heated indoor air and the non-heated basement. However, some the change in energy use of this measure is attributed to to the removal of light fixtures and electric equipment located in the basement. The domestic hot water consumption is assumed to be kept constant even after relocation to the new site. The reason being that the domestic hot water consumption is already determined as the average of a number of households in relation to A_{temp} (appendix 3).

4.2.4 Energy performance evaluation of refurbishment measures

Table 11. Potential improvement of proposed refurbishment measures.

Building element	*Reference*	*Description of refurbishment measure*	*Energy use, E_{bea}/A_{temp}, (kWh/m^2 year)*	*Change in energy use*	*Change in heating energy use, E_{uppv}*
	0	Effects of the 1960's refurbishment	269,8	+ 37.2 %	+ 50,4 %
	BASE LINE	***The building without any implemented refurbishment measures***	***196,7***	-	-
Attic floor	***A***	Replace the sawdust-fill insulation between the rafters with cellulose fiber (loose-fill)	191,4	2,8 %	3,7 %
	B	Replace the sawdust-fill insulation with mineral wool	190,7	3,1 %	4,1 %
	C	Additional attic floor mineral wool insulation (300 mm)	186,3	5,3 %	7,2 %
	D	Additional attic floor mineral wool insulation (500 mm)	184,9	6,0 %	8,1 %
Exterior wall (externally)	***E(1)***	Addition of wood fibre board (50 mm)	185,4	5,7 %	7,8 %
	E(2)	Addition of wood fibre board (80 mm)	181,6	7,7 %	10,4 %
	F	Additional fiberglass insulation (50 mm)	186,5	5,2 %	7,0 %
	G	Addition of aerogel insulation panels (25 mm)	183,0	7,0 %	9,4 %

Exterior wall (internally)	***H***	Addition of wood fibre board (50 mm)	186,5	5,2 %	7,0 %
	I	Addition of EPS board (50 mm)	185,2	5,8 %	7,9 %
	J	Addition of EPS board (100 mm)	182,2	7,4 %	10,0 %
	K	Addition of cellulose insulation panels (50 mm)	185,8	5,5 %	7,5 %
Windows	***L***	Additional glazing $U = 1,3\ W/m^2K$	183,3	6,8 %	9,2 %
	M	High performance windows $U = 0,8\ W/m^2K$	181,2	7,9 %	10,7 %
Bottom floor	***N***	Replace the sawdust-fill insulation between the rafters with cellulose fiber	190,3	3,3%	4,4 %
	O	Replace the sawdust-fill insulation between the rafters with blow-in fibre glass	190,3	3,3 %	4,4 %
Structural foundation (after relocation)	***P***	The basement is replaced by a crawl-space with XPS board insulation	182,9	7,0 %	5,4 %
Roof (in contact with heated spaces)	***Q***	Additional mineral wool insulation board (50 mm)	193,8	1,5 %	2,0 %
Doors	***R***	Replacement of all exterior doors $U = 1,2\ W/m^2K$	194,3	1,2 %	1,7 %

The energy performance in table 11 has been calculated by dividing equation 1 with A_{temp}. E_{uppv} is acquired from the simulation reports. The term represents the heating energy required for maintaining operational temperature within all temperature-controlled spaces/zones. The term also takes internal gains into account. The factors E_{tvv}, E_t and E_f however, maintain their values for almost every simulation scenario (values listed in table 9).

Reduction of thermal transmittance has been derived by evaluating the difference between E_{uppv} after implementing proposed refurbishment measures and $E_{uppv,\ base\ line}$.

4.2.5 Proposed packages of refurbishment measures

As previously mentioned, the refurbishment measures listed in table 11 have been analysed on an individual – case to case – basis. Standard practice endorses refurbishment measures to be considered in packages or sets of compatible measures. Since synergetic effects will surely arise and futher improve their effectiveness. Some interventions are also recommended to be performed simultaneously, for obvious reasons.

Three different packages of refurbishment measures are thus proposed: a light, a moderate and a heavy set of measures. The light package consists of a set of individual measures which have slight to no impact on the heritage values. The moderate package includes individual measures which impact the heritage value moderately or by a lesser degree. The heavy package includes, but is not limited to, individual measures which are slightly acceptable with regard to their impact on heritage values. In other words, the packages have been categorized by their impact on heritage values and their impact on the structure in general. All packages will be evaluated as if the building has been relocated i.e. received a new structural foundation (measure P).

Light refurbishment package (LRP)
The light refurbishment package consists of following measures:

- ❖ *Measure A* Replace the sawdust-fill insulation between the rafters of the attic floor with cellulose fiber (loose-fill)
- ❖ *Measure N* Replace the sawdust-fill insulation between the rafters of the bottom floor with cellulose fiber
- ❖ *Measure P* The basement is replaced by a crawl-space with XPS board insulation.

After implementing aforementioned measures, the building's energy use is calculated to be 175,2 kWh/m^2 which is a reduction of the the heating energy use by approximately 10,7 %, see table 12. This energy improvement has the added benefit of having little to no impact on the heritage values of the building, in the context of how they are defined within this master's thesis.

Measure A would be implemented by removing small portions of the paneling on top of the attic floor and getting access to the cavity between the rafters. After replacing the sawdust-fill insulation with cellulose fiber the original paneling can be reused to close the gaps. A similar technique could be used for the implementation of measure N. However, by removing the bottom paneling of the floor, instead of the top one, the internal floor finishes could be preserved. If these measures are implemented properly, they would impact the heritage values insignificantly.

Moderate refurbishment package (MRP)
The moderate refurbishment package consists of following measures:

- ❖ *Measure A* Replace the sawdust-fill insulation between the rafters of the attic floor with cellulose fiber (loose-fill)
- ❖ *Measure C* Additional attic floor mineral wool insulation (300 mm)
- ❖ *Measure H* Addition of wood fibre board (50 mm) to the inner side of the external wall
- ❖ *Measure L* Additional glazing to the inner side of the window
- ❖ *Measure N* Replace the sawdust-fill insulation between the rafters of the bottom floor with cellulose fiber
- ❖ *Measure P* The basement is replaced by a crawl-space with XPS board insulation.
- ❖ *Measure Q* Additional mineral wool insulation board (50 mm) to the roof in contact with heated spaces
- ❖ *Measure R* Replacement of all exterior doors

These measures affect the building's energy performance by 28,4 %. It is lowered from 196,7 kWh/m^2 to 140,8 kWh/m^2. The measures have an even greater impact on the heating energy use, reducing it by 34,5 %, see table 12.

Measure C would be implemented by assuming easy access to the attic. The addition of wood fibre boards to the inner side of the walls, as measure H suggests, would have implications on the appearance of internal surfaces and would reduce the floor area of the rooms. Nevertheless, no heritage values of particular importance have been identified in reside within the interior of the building. The additional pane of glazing would be installed by constructing a simple frame on the inner side of the existing window. The frame would hold the glas-pane in place by itself and would have limited impact on the aesthetics of the original window. Measure Q would be implemented by removing the 6 mm wood fibre board, the 25 mm wood paneling and the 70 mm mineral wool layer (table 6, roof in contact with heated spaces). The existing mineral wool layer would be replaced by a 120 mineral wool and stud layer and by doing so adding a total of 50 mm of insulation to the roof in contact with heated spaces.

Heavy refurbishment package (HRP)

The heavy refurbishment package consists of following measures:

❖ *Measure B*	Replace the sawdust-fill insulation of the attic floor with mineral wool
❖ *Measure D*	Additional mineral wool insulation to the attic floor (500 mm)
❖ *Measure E(2)*	Addition of wood fibre board (80 mm) to the exterior of the external wall
❖ *Measure I*	Addition of EPS boards to the inner side of the external wall
❖ *Measure M*	Replace existing windows with high performance windows
❖ *Measure O*	Replace the sawdust-fill insulation between the rafters with blow-in fibre glass
❖ *Measure P*	The basement is replaced by a crawl-space with XPS board insulation.
❖ *Measure Q*	Additional mineral wool insulation board (50 mm) to roof in contact with heated spaces
❖ *Measure R*	Replacement of exterior doors

The shared effect of above-listed measures reduces the building's energy use by 32,2 % and the heating energy use by 39,6 %.

Compared results of the three refurbishment packages

Table 12 shows the simulated energy-saving effects the three refurbishment packages would provide if implemented properly. Additional information regarding the energy performance of these refurbishment packages can be found in appendix 16, 17 and 18.

Table 12. Results from the energy simulations when proposed refurbishment packages are implemented.

Package of refurbishment measures	***Building's energy use, Ebea/A_{temp}, (kWh/m^2 year)***	***Heating energy use, E_{uppv} (kWh/m^2 year)***	***Reduction of energy use, Ebea/A_{temp}***	***Reduction of heating energy use, E_{uppv}***
BASE LINE	***196,7***	***145,1***	**-**	**-**
Light refurbishment package (LRP)	175,2	129,6	10,9 %	10,7 %
Moderate refurbishment package (MRP)	140,8	95,1	28,4 %	34,5 %
Heavy refurbishment package (HRP)	133,3	87,7	32,2 %	39,6 %

The reduction of heating energy use (E_{uppv}) can be interpreted as how significantly the proposed refurbishment packages reduce the thermal transmission losses. By comparing the reduction of heating energy instead of total energy use (E_{bea}) the effects of E_{tvv}, E_f and E_t are negated to a certain degree (they still affect the internal gains and indirectly affect E_{uppv}), see figure 14.

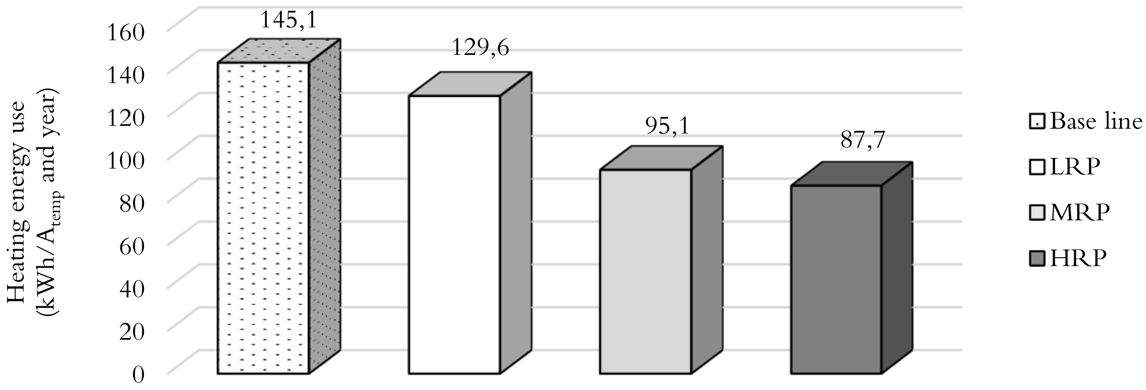


Figure 14. Heating energy use of the base line and the three proposed packages of measures.

Table 13 lists the corresponding primary energy value (EP_{pet}) for each package of measures. Relevant for discussing the performance in relation to Boverket's Building Regulations. The values are derived by extracting information regarding E_{uppv}, E_{tvv}, E_f from every relevant simulated scenario and then applying equation 3.

Table 13. Primary energy value (EP_{pet}) for the proposed refurbishment packages.

Package of refurbishment measures	*Primary energy value, EP_{pet} (kWh/m^2 year)*	*Reduction of the primary energy value, EP_{pet}*
BASE LINE	***128,0***	**-**
Light refurbishment package (LRP)	113,8	11,1 %
Moderate refurbishment package (MRP)	95,7	25,2 %
Heavy refurbishment package (HRP)	91,8	28,3 %

Primary energy values are typically used to evaluate energy performance of newly constructed buildings. It has, nevertheless, been calculated in order to facilitate comparisons to current energy performance requirements.

5 Discussion

5.1 Heritage value assessment

The standard SS:EN 16883:2017 has provided excellent guidance for most steps of the process (figure 2). However, no basis for how the cultural values should be assessed is specified. The assessment of heritage values is primarilty based on the statement from the Swedish Heritage Board and on what has been defined as the character defining elements by the cultural environmental analysis (*Kulturmiljöanalys Malmberget,* 2017). Both the mentioned analysis and the statement emphasize on the social and historical values of the case-building (and its neighbouring buildings). Further interpretation of the heritage value is entirely based on the definitions and concepts presented in section 2. The impact assessment of the heritage value is based entirely on personal interpretation of the stated cultural values, and it is therefore subjective. Subjective interpretation and definitions provided by the Burra Charter have led to an objectivistic assessment, where the materials themselves embody the heritage value. Another assessment that is based on other concepts and/or principles of conservation might come to a different conclusion regarding the acceptability of the refurbishment measures. Establishing a theoretical framework has been a major challenge throughout this project. There are several interpretations of conservation principles and critics of contemporary conservation theory have differing opinons on what should be considered "best-practice".

5.2 Reliability and validity

All assumptions, approximations and simplifications made during the modelling and calculation of the energy performance can reduce the reliability of the results. For example, the climate file for Malmberget was replaced by one representing the climate conditions of Kiruna. Local conditions such as cloudiness, precipitation, wind speeds and temperatures will differ and hence give rise to uncertainties.

The overall energy performance of 196,7 kWh/m^2 (section 4.2.1), as determined by the energy simulation, differs by only 0,9 % from the energy performance of 195 kWh/m^2 which is stated in the energy declaration (appendix 3). It follows that the simulated energy performance falls well within acceptable margins of error (Elmroth, 2015). The energy declaration protocol claims that the energy required for heating spaces (E_{uppv}) is 137 kWh/m^2 (appendix 3). According to the simulation, the equivalent value is 145,1 kWh/m^2 (section 4.2.1), which is an increase of 5,9 %. Such a difference does not, by itself, indicate that anything is wrong with the model. In fact, the model can be considered reliable as long as the difference does not exceed 10 % (Elmroth, 2015). This difference could be explained, at least partially, by estimates made regarding the air infiltration rate since it significantly impacts a building's energy performance.

It has been necessary, in some circumstances, to make assumptions in order to complete the building model. This has only been a required course of action when no other reliable and relevant data has been available. For example, some construction elements and their compositions have not been verified to be completely accurate. This problem arises as a consequence of insufficient documentation and the fact that no invasive examinations of the building and its components have been allowed. Unfortunately, this leads even more uncertainty being introduced.

Energy needs tied to the hot water consumption (E_{tvv}) are determined as the average of 123 apartments from the same neighbourhood (appendix 3). The relatively large sample size should provide enough statistical accuracy to be considered a sufficiently reliable measurement. The same reasoning is applied to the consumption of household (E_t) and property electricity (E_f). As can be seen in table 9, there are some slight variations between the measurements found in the energy declaration and the ones acquired from the simulations. These differences arise from the fact that the lighting conditions (physical properties and number of light fixtures) are not extensively scrutinized. Approximations have been made regarding the physical properties of the lighting fixtures and the number of light fixtures in any given room have been approximated in relation to its area. However, the observed differences between the measured and calculated consumption of electricity is of negligible magnitude. The accumulated consumption of household and property electricity adds up to a totalt of 44 kWh/m^2 and year for both the simulated and the declared consumption, and should therefore, accurately reflect the actual electricity consumption. It follows that the internal heat gain generated by these light fixures and equipment will contribute to the building's energy needs by an, at least in theory, appropriate amount.

5.3 Discussion of the results

The three proposed refurbishment packages (light, moderate and heavy) all impact the energy performance of the building, although, in varying degrees. The light refurbishment package decreases the heating energy use by 10,7 % while essentially having no impact on the heritage values, at least when considering theory, definitions and the expressed heritage values of the case building. The package with moderate impact on heritage values reduces the heating energy use by roughly one third (34,5 %). This package of measures could be applied to the building in the future while only slightly affecting the heritage values of the building. Some of the individual measures in this package could also be considered completely reversible and could therefore justify the alterations made to the construction. The moderate package does not affect the external appearance of the building in any considerable manner, thus not affecting the cultural values perceived by outside observers. In other words, original surfaces and materials of the exterior are preserved. The heavy package on the other hand does affect the external appearance of the building, and while it offers a considerable reduction of the heating energy use (39,6 %), the added benefits might not excuse the impact it has on some of its character defining elements (primarily the facade). A reason this package might even be considered at all is the fact that the facade has already undergone major changes in the 1960's and, as a result, is already irrevocably altered. However, the facade is explicity mentioned as a character defining element in the cultural environment analysis (Kulturmiljöanalys Malmberget, 2017) even though it is not mentioned nor assessed which of the facade's features are most relevant to preserve. This raises the possibility of several interpretations of its value. For example, how much of its value is tied to material authenticity? It can be argued that the preservation of the materials added during the 60's is not of utmost importance. The important aspects to preserve might, in this case, be its aesthetics (design and form). If that is the case, changes to the facade might even be categorized as having less impact on the heritage value of the building. This interpretation would allow the use of reconstruction as a conservation measure. As a consequence, more invasive measures could be allowed in order to improve the building's energy performance.

As the catergorization of the package implies, the heavy refurbishment package would in fact alter the heritage values the most. An optimal solution, when considering the preservation aspects, should therefore exist between the light package and the moderate package or as some combination of the two, depending on which approach is being used during the assessment of the heritage values.

The optimal solution from an economic perspective when considering the energy improvement in relation to investment costs would probably exclude the heavy refurbishment package. The reason is the more invasive measures taken (i.e measures to the facade) and the minor energy efficiency improvements in comparison to the moderate refurbishment package. According to SS:EN 16883:2017 the economic factor should also be considered. Further inquiry into the possibility of improving the energy efficiency should therefore contain an analysis of cost estimations and life-cycle analysis of the proposed refurbishment measures. Some measures might even be excluded due to high investment cost in relation to their impact on the energy efficiency.

Several limitations have been made to limit the scope of this master's thesis, one of which is that only energy-saving measures applied to the building envelope have been considered. This means, for example, that no energy or technical systems inside the building have been altered. State-of-the-art or tailored technical solutions can probably improve the building's energy performance without impacting the heritage values too negatively. If this is the case, the energy performance improvement of the building could be further increased.

Synergestic effects have not been considered. New high-performance windows, for example, would decrease transmission losses and probably air-tighten the construction as well. No such effects have been considered and can, if evaluated properly, further decrease the energy needs of the building.

The results regarding the effectiveness of the proposed refurbishment measures are in line with previous studies. As an example, Luciani et. al, (2018) present similar results regarding the effectiveness of some individual measures.

5.4 Further research

To ensure the viability of the proposed refurbishment measures an extensive analysis is required to determine their impact on the hygrothermal conditions. Such an analysis would have to be performed in order to make any definitive statement regarding the viability of the presented measures. Additional layers of insulating materials will alter the temperature distribution inside the wall, and as a consequence, change the conditions for moisture accumulation. This is not only a requirement according to the standard SS-EN 16883:2017 but also standard industry practice.

Malmberget is currently undergoing an unprecedented transformation. Buildings will be abandoned, moved or demolished as the minig activities gradually require additional space for its operations. Exemptions from any energy performance requirements have been made for those building's that are being moved and this can be considered a lost opportunity. Futher research could try to quantify the potential energy savings the community as a whole could experience by applying energy saving measures to all buildings that will be moved. This could be done by generalizing the building stock and sort them into a manageable number of categories.

As the climate and energy targets heavily focus on reducing the greenhouse gas (GHG) emissions, one interesting field of inquiry would be to evaluate and quantify energy efficiency improvements (of a building or a group of buildings) in terms of reduced GHG emissions.

6 Conclusions

It can be concluded that energy efficiency can be achieved without significantly impacting the heritage values. This conclusion is, however, rather general in its formulation and with a predictable outcome. A more important conclusion can be drawn by analyzing the correlation between the impact on heritage value and energy efficiency improvements (figure 15). The overall trend demonstrates a negative correlation between energy use and the refurbishment packages impact on heritage values, as can be anticipated.

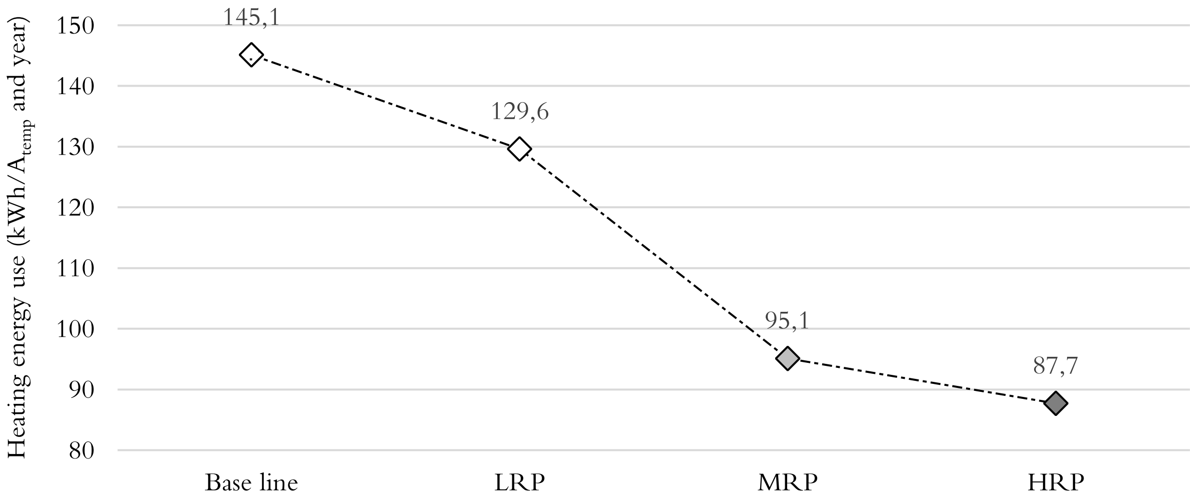


Figure 15. Linear correlation between heating energy use and the three proposed refurbishment packages.

The slope of the dotted lines connecting the base line and the individual refurbishment packages (LRP, MRP and HRP) represents, in a rather simplified manner, the additionally benefits of the measures. The rate by which the measures decrease the heating energy use may exclude the HRP from being considered. In an actual renovation project, it is likely that the assessment of the measures would be based on cost-effectiveness rather than on any other consideration. The results would suggest that both the light and the moderate refurbishment packages, or a combination of the two can be viable options as energy-saving measures, provided that a hygrothermal analysis is carried out which validate their suitability as refurbishment measures.

The aim of this master's thesis is to answer the question: how considerably can energy efficiency of culturally significant buildings be improved without damaging and/or affecting its cultural and aesthetical values. The answer is not straightforward, as it heavily depends on subjective assessments and arbitrary definitions, mainly depending on the possibility of differing interpretations of heritage values. The multitude of methods in which to approach the heritage value assessment will, depending on underlying definitions and theoretical framework, produce different outcomes.

When analyzing the results of the energy performance simulations (section 4.2) an obvious conclusion can be drawn: the light refurbishment package (LRP) decreases the heating energy use by 10,7 % while essentially having no impact on the heritage value of the building. This fact does answer the research question (in its most general connotation) in the case of the studied building. The moderate refurbishment package (MRP) certainly impacts the heritage values, however, this impact has been assessed, as the name suggests, to be limited. This refurbishment package can therefore be considered a viable option. The viability would, in any case, depent on project goals and on their formulations. This moderate refurbishment package might, when compared to similar cases, fall well within acceptable limits regarding its impact on the heritage values.

Conclusions in regard to the problem statement

It has been agreed by the local authorities (Gällivare municipality) and the owners (LKAB Fastigheter) that the case-building will be moved to a new location in the near future. International and national legislation permits the use of exemptions from energy management and thermal insulation requirements (EU 2002/91/EC, EPBD and SFS 2010:900, chapter 8, section 7), as mentioned in the introduction, to protect the built heritage from unwarranted alteration and/or destruction. These exemptions have been considered for the case-building, as its relocation would normally have required more impactful energy efficiency measures to be implemented. Nevertheless, the result of the implemented exemption status is to preserve the heritage values of the building by promoting a non-intervening approach. The results presented in this master's thesis could support the notion that energy improvement measures can be implemented without significantly impacting the heritage values. Similar results have been observed in a previous study by Luciani et.al. (2018). These findings could, if carefully evaluated, facilitate the merging (when appropriate and necessary) of building preservation and energy management, two fields which historically have been seen as incompatible with one another. In other words, preservation of cultural heritage might, if carefully defined and assessed, not immediately exclude the possibility of energy performance measures to be considered. Furthermore, future climate and energy frameworks as well as stricter national energy targets may force energy requirements to be considered to a certain extent even for historically and culturally important buildings and districts. This interpretation of the results is reflected by projects such as *"Spara och Bevara"* and *EFFESUS,* which have stated the importance of energy efficiency improvements of historic buildings.

Effectiveness of the measures

Not even the HRP, which is rather invasive and extensive would achieve the current energy performance requirements stipulated by Boverket's Building Regulations (BBR). This is not by any means surprising, since these stipulations pertain to newly built dwellings. This result may be interpreted as the unlikelihood of heritage buildings to reach current energy requirement standards without affecting their heritage values while only improving the thermal properties of the building envelope. This is a rather general statement since this thesis only has studied one building. Furthermore, one case study is not enough to base such a generalization on. More studies are needed in order to make such a statement reliable.

The results from the case study suggest that the European 2030 energy efficiency target of reducing the energy consumption by 27 % would practically, if only considering the case building, be achieved by implementing the MRP (see table 13 for values regarding the reduction of EP_{pet}). However, reaching national targets or more ambitious and long-term European energy efficiency targets would require additional measures to be implemented. Measures which could alter the heritage values significantly. This would be the case if, for example, alterations were required to be made to the exterior of the building in order to reach energy efficiency targets. Such a measure would most likely change the building's aesthetics and material composition and affect the building's character defining elements.

It is possible to reach current and near future energy targets while only considering changes to the building envelope. However, more ambitious and long-term targets will most likely require optimization of consumption habits, energy systems, introduction of renewable energy sources and on-site energy production and/or the use of high-performance insulation materials. Some of these alternatives might be even more important to consider in the case of historic buildings since more conventional options might be limited if they have too much of an impact on the building's heritage values. In other words, reaching future energy requirements in heritage buildings may only be possible by considering all available options. Especially, as building conservation principles impose technical limitions on certain commonly used retrofit measures.

The standard

The standard SS-EN 16883:2017 has been used to approach the complex issue of improving the energy efficiency of historic buildings and has facilitated the process of producing the proposed energy efficiency measures (LRP, MRP and HRP). Although, these are only options to consider, the impact these measures would have if applied have been quantified to a certain degree. By using this method both qualitive (heritage value assessment) and quantitative (energy efficiency of measures) assessments can be considered simultaneously. The partial application of the procedure suggested by the standard has allowed the development of solutions that balance building preservation and energy performance.

Relevance of continuous improvement of our building stock

Numerous alterations have been made to the case building over time. The 1960's refurbishment, however, can easily be recognized as an attempt to increase the livability and sustainability of the building. Consequently, major changes have already been made to the original structure, some of which are due to energy efficiency concerns. As living-standards have continuously increased over the years so have our expectations of comfort levels. As a consequence, the case-building has been modified to meet the increasing demands. As concerns regarding climate change has been growing continuously over the past few decades so have our demand for energy efficient housing. Institutions, organisations and consumers require even more from our built environment today than was the case even during the 1960's. Additional changes to the building in order to improve its energy efficiency would reflect the current environmental concerns and would be in line with both Swedish and European energy efficiency targets. As alterations were made in the 60's to improve comfort and energy efficiency so can we frame a potential refurbishment of the case building when considering present-day challenges.

Summary

The conclusions presented earlier in this section are summarized as follows:

- Improved energy efficiency can be achieved without significantly affecting the heritage values.
- Both the light and the moderate refurbishment packages (LRP and MRP) or a combination of the two can be viable options as energy saving measures with minimal impact on heritage values.
- The subjectivity of the cultural value assessment process means that different perspectives produce differing retrofitting strategies.
- The viability of the proposed refurbishment packages would depend on project goals and their formulations.
- Legislative policies and exemptions status may lead to non-intervention policies, which could cause property owners and managers to overlook the possibilities of applying energy efficiency measures to historic buildings.
- Current and near-term energy efficiency targets can be achieved without significantly alter the character and the heritage value of the case-building and similar buildings.
- It is possible to reach current and near future climate and energy targets by only considering changes to the building envelope. Long-term targets will, however, probably require optimization of consumption habits, energy systems, introduction of renewable energy sources and on-site energy production.
- The partial application of the procedure suggested by the standard has facilitated the development of solutions that balance both building preservation and energy performance against one another.

7 *References*

Unpublished sources

Energy declaration

Fastighets AB Malmfälten, Energideklarationsprotokoll för Fastighet: Malmberget 8:17 #Puoitak-krokv, ID: 154079 (ver 1.4)

Gällivare bildarkiv

Cover picture (figure 6), Unknown photographer

Figure 4: Unknown photographer

Luossavaara-Kiirunavaara AB (LKAB) Archive

Teknisk beskrivning (technical description) Gällivare Byggnadsnämnd, 19 april 1966, LKAB

Förvaltningen i Malmberget,

Byggnadsavdelningen, 16 mars 1966, Ansvarig ingenjör: Per Bergström

Bostad nr. 158 Hermelinen Omändring av fasader. 9/2 1966. Ritning nr. 2-17-104.

Bostad nr. 158 Hermelinen Omändring av vån. 1 tr. 9/2 1966. Ritning nr. 2-127-102

Bostad nr. 158 Hermelinen Omändring av bottenplan. 9/2 1966. Ritning nr. 2-127-101

Bostad nr. 158 Hermelinen Omändring av grund källarplan. 9/2 1966. Ritning nr. 2-127-100

Bostad nr. 158 Hermelinen Sektioner. 9/2 1966. Ritning nr. 2-127-103

Norrbottens Museum

Report 2009:22

Riksantikvarieämbetet

Riksantikvarieämbetet. (1997). Värdetexter avseende områden i Norrbottens län med kulturmiljövärden av riksintresse enligt 2 kap 6 § NRL. BD län beslut RAÄ 1997-11-17.

Authors:

Sandberg, E. (2005). *Energideklarering av Bostadsbyggnader – Underlagsrapport Systemdelar.*

Published sources

Abel, E., & Elmroth, A. (2016). *Byggnaden som system* (4., [omarb. och förnyad] uppl. ed.). Lund: Studentlitteratur. Retrieved from http://libris.kb.se/resource/bib/19802161

Adalberth, K., Wahlström, A., Abel, E., & Tucán, B. (2008). *Energibesiktning av byggnader* (2. utg. ed.). Stockholm: SIS förlag. Retrieved from http://libris.kb.se/resource/bib/10715171

Baetens, R., Jelle, B. P., & Gustavsen, A. (2011). Aerogel insulation for building applications: A state-of-the-art review. *Energy & Buildings, 43*(4), 761-769. doi:10.1016/j.enbuild.2010.12.012

Björk, C., Nordling, L., & Reppen, L. (2009). *Så byggdes villan;svensk villaarkitektur från 1890 till 2010*. Värnamo: Författarna och forskningsrådet Formas.

Boverkets byggregler. (2017). Karlskrona: Boverket. Retrieved from https://www.boverket.se/globalassets/publikationer/dokument/2017/bbr-2017-konsoliderad-version.pdf

Clarke, J. A., Yaneske, P. P., & Pinney, A. A. (1990). *The harmonisation of thermal properties of building materials*. Watford: BRE Publication. Retrieved from http://www.esru.strath.ac.uk/Documents/89/thermop_rep.pdf

Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings. Retrieved from https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:001:0065:0071:EN:PDF

Directive 2010/31/EU of the European Parliament and of the Council of 19 may 2010 on the energy performance of buildings (recast), 19 May 2010Cong. (2010). Retrieved from https://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF

Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Retrieved from https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:en:PDF

ELIB-rapport nr 4, Forskningsrapport TN: 39. (1992). Gävle. Statens Institution för Byggnadsforskning.

Elmroth, A. (2015). *Energihushållning och värmeisolering. byggvägledning 8. en handbok i anslutning till boverkets byggregler* Retrieved from http://lup.lub.lu.se/record/8056312

Engström, A. (1995). *Bebyggelseinventering*. Luleå: Norrbottens Museum.

Eriksson, J., & Wahlström, Å. (2001). *Reglerstrategier och beteendets inverkan på energianvändningen i flerbostadshus*. Borås: EFFEKTIV. Retrieved from https://www.sp.se/sv/index/research/effektiv/publikationer/Documents/Projektrapporter/Rapport%2001-04.pdf

European Commision. (2016). *Implementing the paris agreement - progress of the EU towards the at least -40% target*. Brussels: Retrieved from https://ec.europa.eu/transparency/regdoc/rep/1/2014/EN/1-2014-689-EN-F1-1.Pdf

European Commission. (2010). *Energy-efficient buildings PPP. multi-annual roadmap and longer term strategy*. Brussels: European Commission.

European Union. (2017). *Smarter, greener,more inclusive? indicators to support the europe 2020 strategy.* (). Luxembourg: Publications Office of the European Union. Retrieved from http://ec.europa.eu/eurostat/documents/3217494/8113874/KS-EZ-17-001-EN-N.pdf/c810af1c-0980-4a3b-bfdd-f6aa4d8a004e

Google Maps. (2018). *Google maps* Google Maps.

Greenspec. (2018). Wood fibre insulation: Introduction. Retrieved from http://www.greenspec.co.uk/building-design/woodfibre-insulation-intro/

Hägerhed-Engman, L. (2006). *Indoor environmental factors and its associations with asthma and allergy among swedish PreSchool children*. Lund.

Heritage Perth. (2019). *The Burra Charter*. Retrieved from https://heritageperth.com.au/your-heritage/the-burra-charter/

Hiller, C. (2007). *Hållbar energianvändning i småhus – etapp II* (doktorandprojekt vid SP Sveriges Tekniska Forskningsinstitut och Lunds Tekniska Högskola).

Hilliaho, K., Mäkitalo, E., & Lahdensivu, J. (2015). Energy saving potential of glazed space: Sensitivity analysis. *Energy & Buildings, 99*, 87-97. doi:10.1016/j.enbuild.2015.04.016

Historic England. (2008). *Conservation principles, policies and guidance*. London.

Historic England. (2016a). *Energy efficiency and historic buildings insulating early cavity walls*. London: Historic England. Retrieved from https://content.historicengland.org.uk/images-books/publications/eehb-early-cavity-walls/heag083-early-cavity-walls.pdf/

Historic England. (2016b). *Energy efficiency and historic buildings insulating solid walls*. London: Historic England. Retrieved from https://content.historicengland.org.uk/images-books/publications/eehb-insulating-solid-walls/heag081-solid-walls.pdf/

Historic England. (2016c). *Energy efficiency and historic buildings insulating timber-framed walls*. London: Historic England. Retrieved from https://content.historicengland.org.uk/images-books/publications/eehb-insulating-timber-framed-walls/heag071-insultating-timber-framed-walls.pdf/

ICOMOS. (1994). *The nara document on authenticity*. Nara: International Council on Monuments and Sites. Retrieved from https://whc.unesco.org/document/116018

ICOMOS Austrailia. (2013). *The Burra Charter: The Australia ICOMOS charter for places of cultural significance*. Burwood: Australia ICOMOS. Retrieved from http://australia.icomos.org/wp-content/uploads/The-Burra-Charter-2013-Adopted-31.10.2013.pdf

Johansson-Erik. (1994). Woodwool slabs : Manufacture, properties and use. *Building Issues, 6*(3) Retrieved from https://lucris.lub.lu.se/ws/files/4583749/4359020.pdf

Kulturmiljöanalys malmberget. (2017). Stockholm: Tyréns.

Künzel, H. (1998). Effect of interior and exterior insulation on the hygrothermal behaviour of exposed walls. *Materials and Structures, 31*(2), 99-103. doi:10.1007/BF02486471

Kurnitski, J., Saari, A., Kalamees, T., Vuolle, M., Niemelä, J., & Tark, T. (2011). Cost optimal and nearly zero (nZEB) energy performance calculations for residential buildings with REHVA definition for nZEB national implementation. *Energy & Buildings, 43*(11), 3279-3288. doi:10.1016/j.enbuild.2011.08.033

Liu, L., Moshfegh, B., Akander, J., & Cehlin, M. (2014). Comprehensive investigation on energy retrofits in eleven multi-family buildings in sweden. *Energy & Buildings, 84*, 704-715. doi:10.1016/j.enbuild.2014.08.044

Lopez Hurtado, P., Rouilly, A., Vandenbossche, V., & Raynaud, C. (2016). A review on the properties of cellulose fibre insulation. *Building and Environment, 96*, 170-177. doi:10.1016/j.buildenv.2015.09.031

Luciani, A., Lidelöw, S., Bhattacharjee, S., & Örn, T. (2018). *The challenge of energy efficiency in kiruna's heritage buildings*. Luleå: Luleå University of Technology.

Lövehed, L. (1995). *Villa '95: ett yt- och energisnålt enfamiljshus*. (Rapport TABK; Vol. 3029). Avd Installationsteknik, LTH, Lunds universitet.

Petersson, B. (2009). *Tillämpad byggnadsfysik* (4:3 ed.). Lund: Studentlitteratur.

Petzet, M. (2004) *Principles of preservation: An introduction to the International Charters for Conservation and Restoration 40 years after the Venice Charter.* In: International Charters for Conservation and Restoration. Monuments & Sites, I . ICOMOS, München, pp. 7-29. ISBN 3-87490-676-0 [Book Section]

Pracchi, V. (2014). *Historic Buildings and Energy Efficiency, The Historic Environment: Policy and Practice*. Volume 5, Issue 2, pages 210-225.

Practical Conservation Guide for Heritage Properties, Insulation. (2017). Waterloo. Retrieved from https://www.regionofwaterloo.ca/en/resources/Practical_Guide_Insulation_2017-access.pdf

Robertsson, S. (2002). *Fem pelare - En vägledning för god byggnadsvård* (1. [uppl.] ed.). Stockholm: Riksantikvarieämbetets förl. Retrieved from http://libris.kb.se/resource/bib/8419004

Royapoor, M., & Roskilly, T. (2015). Building model calibration using energy and environmental data. *Energy & Buildings, 94*, 109-120. doi:10.1016/j.enbuild.2015.02.050

SCB. (2018). *Genomsnittligt antal personer per hushåll efter region, boendeform, lägenhetstyp och år*. Stockholm: Statistiska Centralbyrån (SCB).

SFS 2010:900. *Plan- och bygglagen/Planning and Building Act.* Stockholm: Näringsdepartementet RSN.

Skarning, J., Hviid, A., & Svendsen, S. (2016). Roadmap for improving roof and fac¸ ade windows in nearly zero-energy houses in europe. *Energy and Buildings,* (116), 602-613. Retrieved from https://www.sciencedirect.com/science/article/pii/S0378778816300378

SVEBY. (2012). *Brukarindata bostäder*. Stockholm: SVEBY. Retrieved from http://www.sveby.org/wpcontent/uploads/2012/10/Sveby_Brukarindata_bostader_version_1.0.pdf

SS-EN 15603:2008 Energy performance of buildings – Overall energy use and definition of energy ratings. European Committee for Standardization, Brussels.

SS-EN 16883:2017 Conservation of cultural heritage – Guidelines for improving the energy performance of historic buildings. European Committee for Standardization, Brussels.

Swedish Energy Agency. (2018). *Energy in sweden 2017*. Bromma: Swedish Energy Agency. Retrieved from www.swedishenergyagency.se

The Getty Conservation Institute. (2002). *Assessing the values of cultural heritage*. Los Angeles: Retrieved from https://www.getty.edu/conservation/publications_resources/pdf_publications/pdf/assessing.pdf

Vestlund, J. (2010). Energieffektivisering. *Norrbottens läns hembygdsförenings tidskrift* (pp. 287). Luleå: Stiftelsen Norrbottens museum.

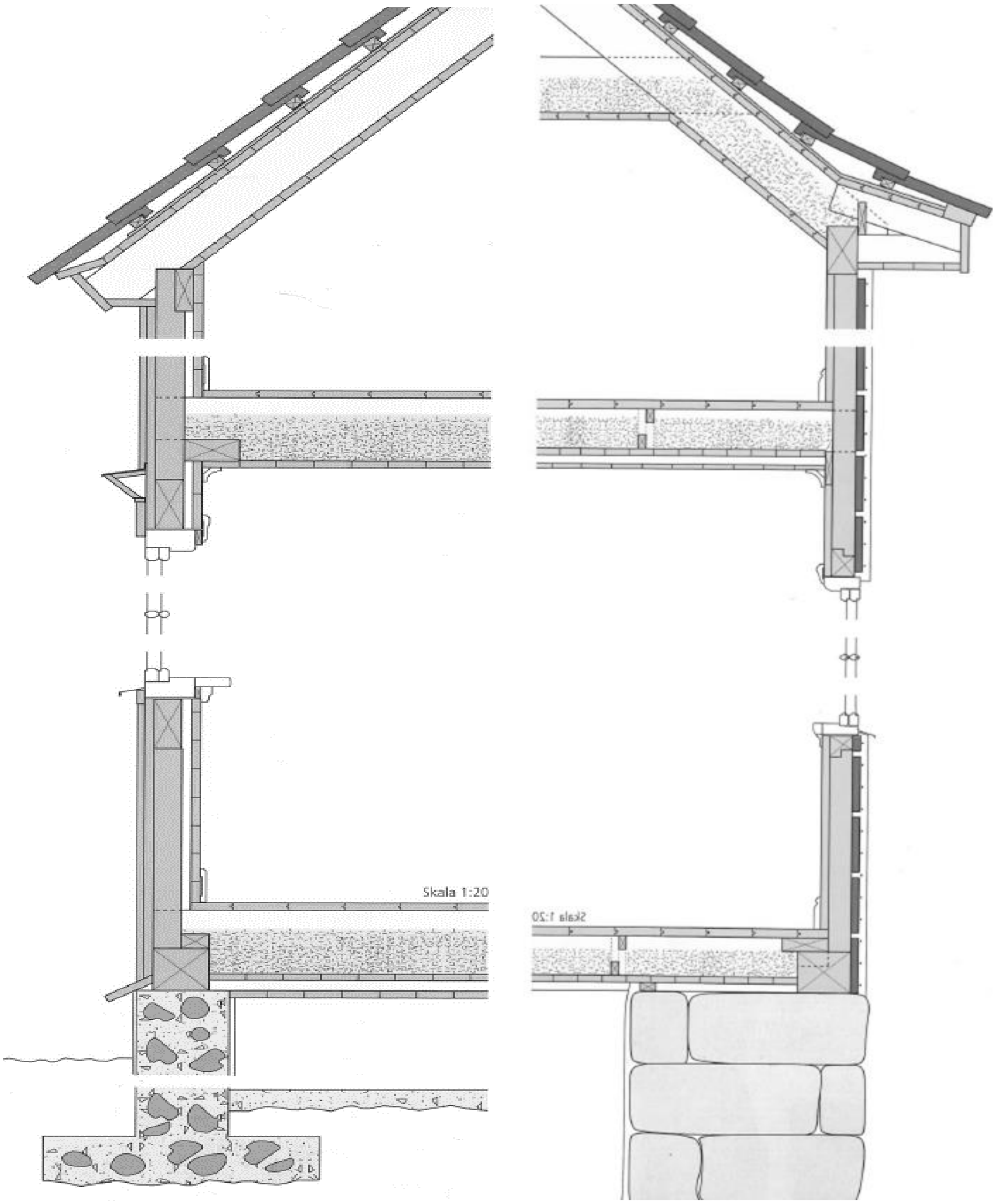
8 Appendices

Appendix 1 – Quality of thermal bridges

Thermal bridge *Structural connection*	*Heat conductivity* *(W/K/m joint)*	*Quality*
External wall / internal slab	0.05	Typical
External wall / internal wall	0.03	Typical
External wall / external wall	0.08	Typical
External windows perimeter	0.03	Typical
External doors perimeter	0.03	Typical
Roof / external wall	0.09	Typical
External slab / external walls	0.14	Typical
Balcony floor / external walls	0.2	Typical
External slab / internal walls	0.03	Typical
Roof / internal walls	0.03	Typical

Note: Standard/typical values according to the software (IDA ICE) have been assumed for the heat conductivity of the thermal bridges.

Appendix 2 – Construction solutions from the early 20th century



Note: Two typical timber frame constructions from 1910-1920 (Björk et al., 2009). Especially take note of the roof construction of the rightmost structure, the roof part which is in contact with the heatead indoor environment is insulated with sawdust, it's the most common insulating material for these types of buildings built during this time period. The picture is not properly scaled.

Appendix 3 – Energy declaration protocol, part 1

Energideklarationsprotokoll för Fastighet: Malmberget 8:17 #Puoitakv-Krokv

Ägare: Fastighets AB Malmfälten *Org.nr.:* 556009-8849 *Typ:* Vanlig deklaration *Tidigare deklarerad:* Nej
Adress: Stallvägen 13, 98332 MALMBERGET *Telefon:* 0970 - 76730

	kWh	kWh/m²
Värme	2 115 086	174
varav varmvatten	454 157	37
Fastighetsel	154 908	13
Komfortkyla	0	0
Verksamhetsel	215 550	18
Hushållsel	367 193	30

Kontroll av energi till varmvatten

Total vattenförbrukning, m³	12 300
Varmvattentemperatur, °C	61
Max om allt värms, kWh	756 928

EP betyder EnergiPrestanda och är energianvändningen för uppvärmning, varmvatten, fastighetsel och komfortkyla dividerat med uppvärmd yta. Hushållsel och verksamhetsel ska inte medräknas.
Beräkningen gör att du kan jämföra ditt hus med andra jämförbara hus. I deklarationen hittar du det definitiva värdet på EP och jämförelsetal. Avvikelsen mellan EP i det här protokollet och deklarationen beror på att det senare är korrigerat för periodens utomhustemperatur.

Åtgärd	Typ	Investering kr	Energibesparing kWh	Besparing år 1 kr	Återbetalningstid år	Nuvärde kr	Sparkostnad kr/kWh	Minskat koldioxid ton/år
Puoitakvägen 12								
*/ Tilläggsisolera vind	Bygg	497 284	218 875	176 766	3	3 165 237	0,11	75
*/ Byte av termostatvent +injustering	Styr	528 000	210 117	170 195	3	1 742 948	0,19	67
*/ Insättning av tredje ruta	Bygg	1 453 200	262 855	212 913	7	1 387 742	0,41	84

*/ Åtgärden avser samtliga hus men registreras på den här adressen

	Besparing:	el, kWh	värme, kWh	kyla, kWh	DoU, kr	Brukstid, år
Klimatskal						
Tilläggsisolera vind	I vissa byggnader har vindsutrymmet ej kunnat besiktigas och i dessa byggnader har andelen tilläggsisolerbar antagits var 50% av byggnadsytan. En vidare inventering av dessa är att rekomendera.	8 875	210 000	0	0	25
Insättning av tredje ruta	U-värdet sänks från 2,7 till 1,3 W/m2K.	0	262 855	0	0	15
Värmesystem						
Byte av termostatvent +injustering	Termostatventilerna är gamla och behöver bytas och värmesystemet injusteras. En hög sekundär returtemperatur och stor skillnad mellan sek retur och primär returtemperatur indikerar att undercentralen och värmeväxlaren behöver ses över.	0	210 117	0	0	15
Totalsumma		**8 875**	**682 972**	**0**	**0**	

Utbildning av driftspersonalen kring byggnadernas energisystem, att se möjligheter till besparingar och hur anläggningens skötsel och drift påverkar energianvändningen kan ge både snabba och bestående besparingar.

Ökad användning av energistatistik för boende och driftspersonal är ett bra verktyg för att synliggöra förbrukningen av värme och el. Detta är första steget mot ett förändrat beteende som minskar energianvändningen.

Vid renovering av fasader bör tilläggsisolering beaktas. Denna åtgärd är sällan lönsam för befintliga byggnader, men kan vara det då renovering sker av andra skäl.

Styrning av belysning i allmäna utrymmen (trapphus, tvättstuga, förråd, mm) kan ofta drastiskt förkorta brinntiden och därav minska elanvändningen för belsyningen. Det finns idag många smarta varianter av styrning som passar för olika tillämpningar.

ID: 154079 (ver 1.4)

Appendix 3 – Energy declaration protocol, part 2

Byggnaden - Egenskaper

Typkod 320 - Hyreshusenhet, huvudsakligen bostäder		Byggnadskategori Flerbostadshus
Byggnadens komplexitet ◉ Enkel ○ Komplex	Byggnadstyp Friliggande	Nybyggnadsår 1914

Atemp (exkl. Avarmgarage)	
◉ Mätt värde	12 180 m²
○ Omvandlat från BOA/LOA	
○ Omvandling för kontorsbyggnad (>=75%)	
○ Omvandlat från BRA	
○ Omvandlat från BTA	
BOA 8 865 m²	LOA 0 m²
BRA m²	BTA m²
Antal källarplan uppvärmda till >10°C (exkl.garageplan)	0
Avarmgarage	0 m²
Antal våningsplan ovan mark	2
Antal trapphus	25
Antal bostadslägenheter	123
Projekterat genomsnittligt ventilationsflöde i lokaler och specialbyggnader	l/s,m²

Verksamhet
Fördela enligt nedan:

	Procent av Atemp (exkl. Avarmgarage)
Bostäder (inkl. biarea, t.ex. trapphus och uppvärmd källare)	93
Hotell, pensionat och elevhem	
Restaurang	
Kontor och förvaltning	0
Butiks- och lagerlokaler för livsmedelshandel	
Butiks- och lagerlokaler för övrig handel	0
Köpcentrum	
Vård, dygnet runt	
Vård, dagtid (samt serviceboende, frisersalong o. dyl)	
Skolor (förskola-universitet)	
Bad-, sport-, idrottsanläggningar (ej utomhusarenor)	
Teater-, konsert-, biograflokaler och övriga samlingslokaler	7
Övrig verksamhet - ange vad	
Summa	100

Appendix 3 – Energy declaration protocol, part 3

Energianvändning

Vilken 12-månadsperiod avser energiuppgifterna? (ange första månaden i formatet ÅÅMM)

0711 - 0810

Hur mycket energi har använts för värme och kyla angivet år (ange mätt värde om möjligt)?
Angivna värden skall inte vara normalårskorrigerade

			Mätt värde	Fördelat värde
Fjärrvärme (1)	2 101 165	kWh	○	◉
Eldningsolja (2)		kWh	○	○
Naturgas, stadsgas (3)		kWh	○	○
Ved (4)		kWh	○	○
Flis/pellets/briketter (5)		kWh	○	○
Övrigt biobränsle (6)		kWh	○	○
El (vattenburen) (7)		kWh	○	○
El (direktverkande) (8)	13 921	kWh	○	◉
El (luftburen) (9)		kWh	○	○
Markvärmepump (el) (10)		kWh	○	○
Värmepump-frånluft (el) (11)		kWh	○	○
Värmepump-luft/luft (el) (12)		kWh	○	○
Värmepump-luft/vatten (el) (13)		kWh	○	○
Summa 1-13 [1] **(Σ1)**	2 115 086	kWh		
Varav energi till varmvattenberedning	454 157	kWh	○	◉
Fjärrkyla (14)		kWh	○	○

Finns solvärme? ○ Ja ◉ Nej

Om ja, ange total solfångararea m^2

Omvandlingsfaktorer för bränslen i tabellen nedan gäller om inte annat uppmätts:

Eldningsolja	10 000 kWh/m^3
Naturgas	11 000 kWh/1 000 m^3 (effektivt värmevärde)
Stadsgas	4 600 kWh/1 000 m^3
Pellets	4 500-5 000 kWh/ton, beroende av träslag och fukthalt

Källa: Energimyndigheten
För övriga biobränsle varierar värmevärdet beroende av sammansättning och fukthalt. Det är expertens ansvar att omräkna bränslets vikt eller volym till energi på ett korrekt sätt.

Övrig el (ange mätt värde om möjligt)
Angivna värden skall inte vara normalårskorrigerade

			Mätt värde	Fördelat värde
Fastighetsel (15)	154 908	kWh	○	◉
Hushållsel (16)	367 192	kWh	○	◉
Verksamhetsel (17)	215 550	kWh	○	◉
Komfortkyla (18)	0	kWh	○	◉
Summa 7-13,15-18 [2] **(Σ2)**	751 571	kWh		
Summa 1-15,18 [3] **(Σ3)**	2 269 994	kWh		
Summa 7-13,15,18 [4] **(Σ4)**	168 829	kWh		

Ort (graddagar)	Normalårskorrigerat värde (graddagar)	Ort (Energi-Index)	Normalårskorrigerat värde (Energi-Index) [5]
Gällivare A	2 378 954 kWh	Gällivare	2 376 420 kWh

Energiprestanda	...varav el	Referensvärde 1 (enligt nybyggnadskrav)	Referensvärde 2 (statistiskt intervall)
195 kWh/m^2,år	14 kWh/m^2,år	129 kWh/m^2,år	191 - 237 kWh/m^2,år

[1] Energi för uppvärmning och varmvatten
[2] El totalt
[3] Värme, kyla och fastighetsel
[4] El exklusive hushållsel och verksamhetsel
[5] Underlag för energiprestanda

Appendix 4 – Technical description, part 1

TEKNISK BESKRIVNING

[ ] Nybyggnad [X] Till-, på- eller ombyggnad [ ] Annat arbete

Kommun: Gällivare
Länsbeteckning: BD
Fastighetsbeteckning: Hermelin bost. 164 och 158 Puoitakvägen 3 resp. 5
Sökandens namn: Luossavaara-Kiirunavaara AB
Sökandens adress och telefon: Malmberget tel. 0970/21000

Grund

Undergrundens beskaffenhet och möjlighet: Pinnmo

Grundläggningssätt: Bottensulor av granit

Yttre grundmurar: Granit

Värmeisolering: 5 cm träullsplatta i matkällare

Vattenisolering

Sockel

Dränering

Inre grundmurar: Granit och 20 cm btg-hålsten

Väggar

Ytterväggar: På bef. vägg av 3" plank, papp, reglar, panel och invändig träfiberplatta. Utvändigt 5 cm mineralullsmatta, reglar för 1" luftrum och panel

Innerväggar, bärande: 3" plank, reglar, panel och träfiberplattor på båda sidorna.

Lägenhetsskiljande: Bef. vägg av 3" plank och panel kompl. med 5 cm frihängande mineralullsmatta 2" x 2" reglar, inv. bekl. 19 mm asfaboard.

Trapphusväggar: Lika lägenhetsskiljande vägg + gipsplattor

Mot ouppvärmt utrymme: 3" plank, reglar, fyllning med kutterspån, papp, panel och träfiberplattor på båda sidor.

Övriga: Reglar 19 mm asfaboard eller 6 mm träfiberplatta. I vägg mot badrum sättes 5 cm mineralullsmatta och panel.

Brandmurar

Bjälklag

Källarbjälklag: 3" x 9" bjälkar c/c 60 cm, panel, 1" trossbotten, papp, sågspånsfyllning, trägolv enligt rumsbeskrivning.

Mellanbjälklag: 3" x 9" bjälkar c/c 60 cm, panel, 1" trossbotten, papp, sågspånsfyllning, undertak av 2" x 4" reglar, 2,5 cm mineralullsmatta, panel och träfiberplatta resp. papp.

Vindsbjälklag: Lika mellanbjälklag men utan golvbräder.

Bjälklag under badrum: 7 cm mineralullsplatta, golvträ hård träfiberplatta. Golvbeklädnad av pegulan.

Altanbjälklag

Balkonger: Stålkonstruktion

Trappor: Trä

Tak

Yttertak, snedtak och hanbjälklag: 3" x 7" högben, panel, papp och plåt. Tak i trapphus kompl. inv. med 7 cm mineralullsmatta, reglar och panel samt invändigt beklädd med träfiberplatta.

Tillhör GÄLLIVARE BYGGNADSNÄMNDS beslut § 204 / 205 vid sammanträde den 19/4 1966 belygar.

Nr 162 — Kommunaltidsbolaget

Source: Luossavaara-Kiirunavaara AB (LKAB) Archive

Appendix 4 – Technical description, part 2

Rumsbeskrivning — Angiv material och målningsbehandling. Använd helst hänvisning enligt Bygg-AMA 1950

Trapphus:

golv

Linoleum

väggar

Hård träfiberplatta Vv 4037

tak

Hård träfiberplatta Vv 4037

snickerier

Enl. SIS Vv 5022

Rum:

golv

Linoleum. Vardagsrum parkett

väggar

Tapeter

tak

Papp Vjt 5061

snickerier

Enl SIS Vv 5022

Kök:

golv

Linoleum

väggar

Hård träfiberplatta Vv 4037

tak

Hård träfiberplatta Vv 4037

snickerier

Enl. SIS Vv 5022

Yttre målningsarbeten:

snickerier

Enl. SIS Vv 5022

plåt- och smidesarbeten

Vv 6061

Övriga upplysningar

Byggnadsnämndens yttrande

Byggnadslov

- [ ] lämnat
- [ ] icke lämnat

Undersökning för best. av grundläggning

- [ ] erfordras
- [ ] erfordras ej

För området gäller

- [ ] stadsplan
- [ ] byggnadsplan
- [ ] avstyckn-plan
- [ ] utomplansbest.
- [ ] inga byggn.regl. bestämmelser
- [ ] byggnadsförbud

Fastigheten är vederbörligen bildad

- [ ] Ja år ....
- [ ] Nej

Byggn-ritn o byggn-beskrivn kan godkännas för byggnadslov

- [ ] utan erinran
- [ ] med erinran enl bil yttrande

Byggnadsnämndens underskrift

den ....

Värmeinstallation m m

Värmesystem

- [x] Varmvatten
- [ ] Varmluft
- [x] Radiatorer
- [ ] Slingor i golv
- [ ] Varmluftsinblåsning
- [ ] Varmt golv
- [ ] Själv-cirkulation
- [x] Pump-cirkulation
- [ ] Ett-rörs-system
- [x] Tvårörs-system

Pannutrustning

- [ ] Varmvattenpanna
- [ ] Varmluftspanna

Panntyp / Storlek, m² / Kcal./tim

Bränsle

- [ ] Olja
- [ ] Koks/Ved
- [ ] Gas
- [ ] El

Oljeeldningsaggregat

- [ ] Högtryck
- [ ] Lågtryck
- [ ] Förgasningsbrännare

Material i rörledningar

stål

Material i skorsten

Brant tegel 6" x 12"

Ventilation

- [x] Självdrag
- [ ] Mekanisk ventilation

Evakueringspipors dimensioner — Kök: 6" x 6" — Rum: 6" x 6"

Badrum: 6" x 6" — Wc — Tvättstuga: 6" x 6" — Torkrum

Övriga upplysningar

Värmesystemet anslutes till värmecentral för ~~[illegible]~~området

[illegible]

Ansvarig arbetsledare

Ingenjör Per Bergström

Arkitekt

LKAB

Byggnadskonstruktör

LKAB

Värme- och ventilationskonstruktör

LKAB

Sökandens underskrift

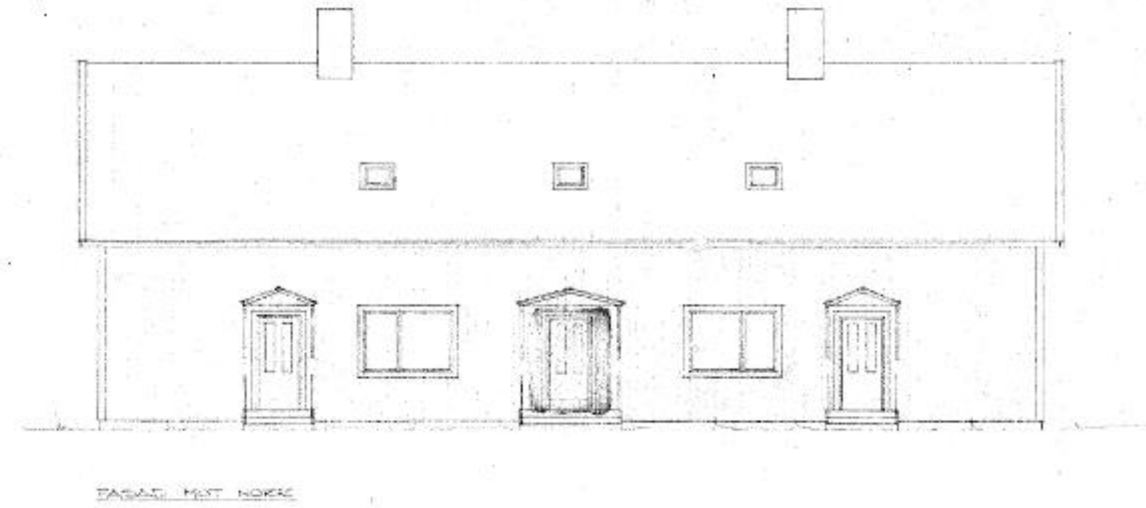
Malmberget den 16.3.66

LUOSSAVAARA-KIIRUNAVAARA AKTIEBOLAG
FÖRVALTNINGEN I MALMBERGET
Byggnadsavdelningen

[illegible] Per Bergström

Source: Luossavaara-Kiirunavaara AB (LKAB) Archive

Appendix 5 – Puoitakvägen 5, facades



Bostad nr. 158 Hermelinen Omändring av fasader. 9/2 1966. Ritning nr. 2-17-104.

Source: Luossavaara-Kiirunavaara AB (LKAB) Archive

Appendix 6 – Energy declaration protocol: Malmberget 8:17 #Puoitakv-Krokv, part 1

Puoitakvägen 3

Energideklarationsprotokoll för Fastighet: Malmberget 8:17 #Puoitakv-Krokv

BYGGNADENS NUMMER ENLIGT LANTMÄTERIET #:70 **BYGGNADENS ID ENLIGT LANTMÄTERIET:1-1248272**

Byggnad: Puoitakvägen 3 98332

Kommentar: konstruktionsprncip som nr 3

Typkod: 320 - Hyreshusenhet, huvudsakligen bostäder

Ny-/ombyggnadsår: 1898 / 1967 *Byggnadstyp:* Friliggande

Atemp, m²: 432 mätt värde *Area - BOA/LOA, m²:* 354 /

Antal lägenheter: 4 *trapphus:* 1 *Avarmgarage, m²:* 0

Antal plan o/u mark: 2 / 0 *Proj. fl., l/s och m²:* 0

Verksamhet, andel i % av A-temp:					
Bostäder:	100	*Livsmedelshandel:*	0	*Skolor (förskola-universitet):*	0
Hotell, pensionat och elevhem:	0	*Övrig handel:*	0	*Bad-, sport- idrottsanläggningar:*	0
Restaurang:	0	*Köpcentrum:*	0	*Teater, samlingslokal m m:*	0
Kontor och förvaltning:	0	*Vård, dygnet runt:*	0		0
		Vård, dagtid:	0	*Summa:*	100

Väderstreck	Konstruktion	Ytskikt	Area, m²	Tjocklek, mm	Skick
Flera väderstreck	År 1900- med renovering. Liggtimmer med 50 mm minull U=0,4	Träpanel, stående	288	50	Ok

Väderstreck	Placering	Fönstertyp	Årtal	Karmtyp	Antal	Area tot., m²	Tätningslist	Skick
Alla	Fasad	1950-tal 1+1-glas i kopplade bågar U-2,7	1950	Trä	22	42	Ok	

Ommålningsbehov samt energiteknisk kvalité undermålig

Väderstreck	Material	Stängare	Tätningslist	Antal	Area, m2/st	Skick
Nord	trä	Nej	tätar ej	3	2,5	Behöver justera

Taktyp	Kallt tak	*Isolering*	Kutterspån		
Skick	ej besiktningsbart svallis vid takfoten	*Tjocklek - ursprunglig, mm*	220	*Tjocklek - tilläggs, mm*	
Luftning		*Ytterligare isolerbar area, m²*		*med tjocklek , mm*	
Anteckningar					

Byggnaden ventileras med självdrag

Terminalenhet	Kopplingsprincip	Reglering	Antal	Årtal	Injustering	dito, datum	Skick	Anteckningar
Vattenburna radiatorer	Tvårörssystem	Maxbegränsande	38	25			Ok	

Appendix 6 – Energy declaration protocol: Malmberget 8:17 #Puoitakv-Krokv, part 2

Puoitakvägen 5

Energideklarationsprotokoll för Fastighet: Malmberget 8:17 #Puoitakv-Krokv

BYGGNADENS NUMMER ENLIGT LANTMÄTERIET #:69 **BYGGNADENS ID ENLIGT LANTMÄTERIET:1-1295433**

Byggnad:	Puoitakvägen 5 98332			*Kommentar:*
Typkod:	320 - Hyreshusenhet, huvudsakligen bostäder			som puojtakv 3
Ny-/ombyggnadsår:	1897 / 1967	*Byggnadstyp:*	Friliggande	
Atemp, m²:	432 mätt värde	*Area - BOA/LOA, m²:*	354 /	
Antal lägenheter:	4 *trapphus:* 0	*Avarmgarage, m²:*	0	
Antal plan ö/u mark:	2 / 0	*Proj. fl., l/s och m²:*	0	

Verksamhet, andel i % av A-temp:					
Bostäder:	100	*Livsmedelshandel:*	0	*Skolor (förskola-universitet):*	0
Hotell, pensionat och elevhem:	0	*Övrig handel:*	0	*Bad-, sport- idrottsanläggningar:*	0
Restaurang:	0	*Köpcentrum:*	0	*Teater, samlingslokal m.m:*	0
Kontor och förvaltning:	0	*Vård, dygnet runt:*	0		0
		Vård, dagtid:	0	*Summa:*	100

Byggnaden ventileras med självdrag

Important information

A_{temp} = 432 m^2 (measured value).

Puoitakvägen 5 has a similar construction as Puoitakvägen 3.

Appendix 7 – Dimensions, thermal conductivity, thermal resistance and U-value of composite material layers

Källarbjälklag (Bottom floor)	***d*** mm	**λ** W/mK	***R*** m^2K/W	***U-värde*** W/m^2K
R_{se}	-	-	0,130	
Träfiberplatta	25	0,14	0,179	
Reglar + Sågspånsfyllning	225	0,14/0,1	2,143	
Papp	-	-	-	
Trossbotten	25	0,14	0,179	
R_{si}	-	-	0,130	
Σ*R*_*homogena skikt*			0,617	
Σ*R*_*i*			2,760	***0,362***

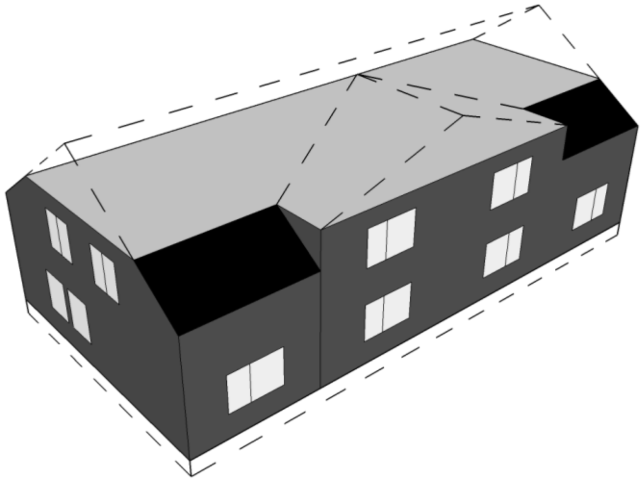
R_{se} och R_{si}
För praktiska beräkningar bortser man från variationer och antar rimliga medelvärden för dessa övergångsmotstånd. R_{si} = 0,13 m^2K/W (för konstruktioners innerytor) och R_{se} =0,04 m^2K/W (för konstruktioners ytterytor). (Petersson s.245).

Homogena skiktet

$$R_i = R_{si} + \sum \left(\frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \ldots + \frac{d_n}{\lambda_n}\right) + R_{se}$$

R_{si} = Inre övergångsmotstånd (m^2K/W)
R_{se}= Yttre övergångsmotstånd (m^2K/W)
d_i = Skikttjocklek för materialskiktet (m)
λ_i = Värmeledningsförmåga för materialskiktet (mK/W)
R_i = Homogena skiktens totala värmemotstånd (m^2K/W)

Appendix 8 – Enclosing/external surface area ($A_{external\ surface}$)



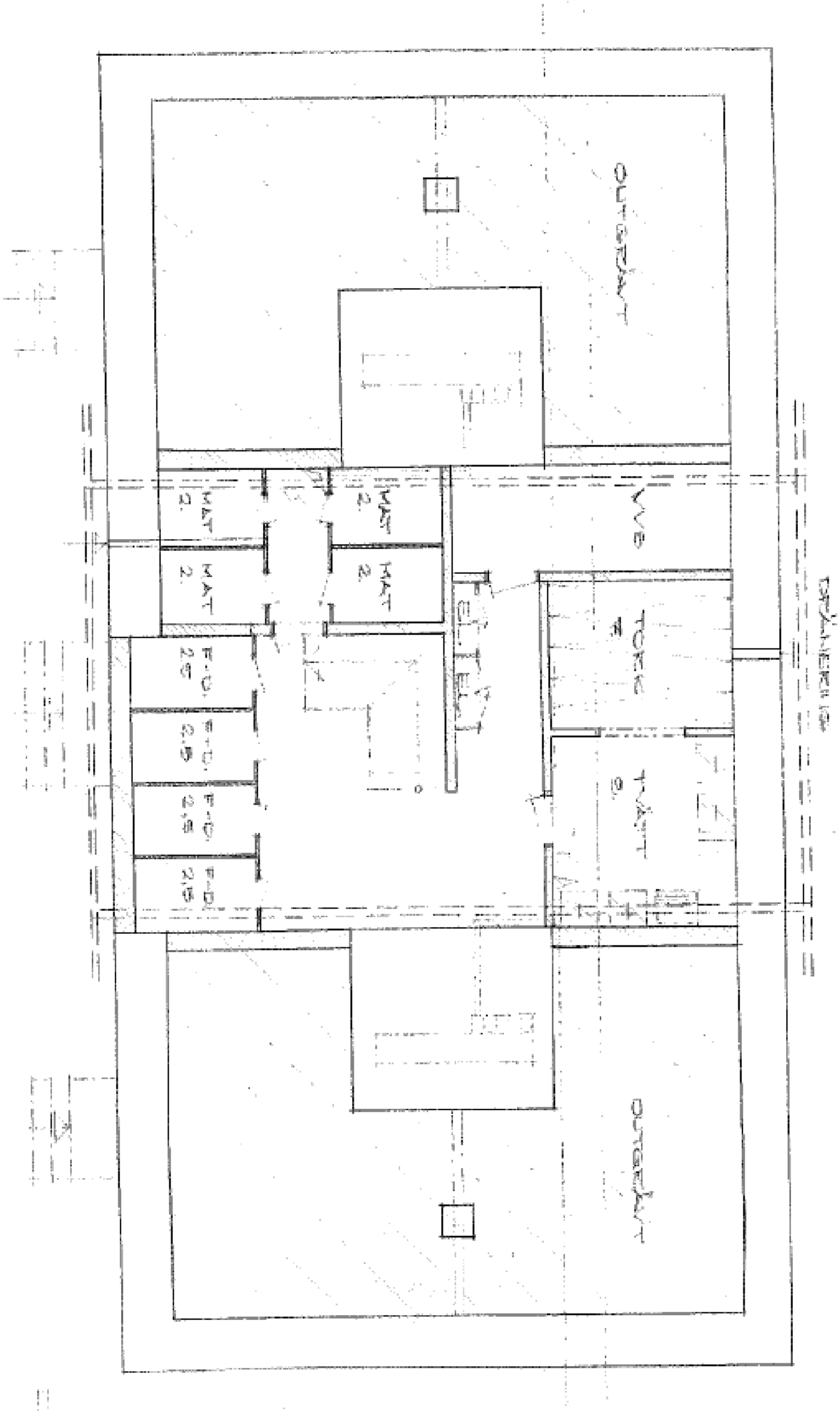
Fascade orientation	*Window area (m^2)*	*Quantity*	*Total Area (m^2)*
North	1,12	6	6,72
	1,71	6	10,26
East	0,98	4	3,92
	1,8	2	3,6
South	1,12	2	2,24
	1,71	2	3,42
West	0,98	4	3,92
	1,8	2	3,6
$A_{windows}$	–	–	37,68

Fasace orientation	*Door area (m^2)*	*Quantity*	*Total area (m^2)*
North	–	–	
East	–	–	
South	1,6	3	4,8
West	–	–	
A_{doors}	–	–	4,8

Note: The rest of the building element areas have been derived from the IDA ICE model. $A_{attic\ floor}$ has been calculated by adding the ceiling area of all zones in contact with the attic floor. A_{roof} is only the part of the roof which is in direct contact with heated indoor air. A_{walls} has been calculated from the building body and geometry. $A_{basement\ floor}$ is just A_{temp} divided by a factor of 2. The figure above displays most, but not all, of the building parts which together form the enclosing area (A_{ext}) of the building in direct contact with heated indoor air.

Buidling element	*Area (m^2)*
$A_{attic\ floor}$	159,1
$A_{windows}$	37,68
A_{doors}	4,8
A_{roof}	73,58
A_{walls}	269,78
$A_{basement\ floor}$	216
$A_{external\ surface}$	760,94

Appendix 9 – Basement floor plan

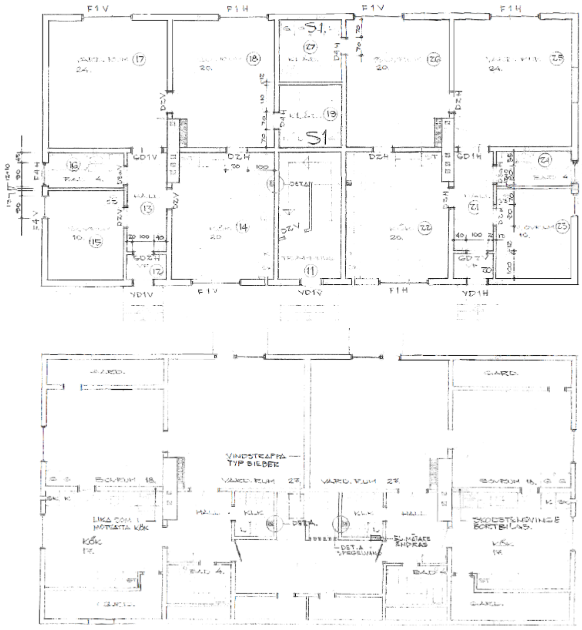


Bostad nr. 158 Hermelinen Omändring av grund källarplan. 9/2 1966. Ritning nr. 2-127-100

Note: Lack of measurements

LKAB Arkiv

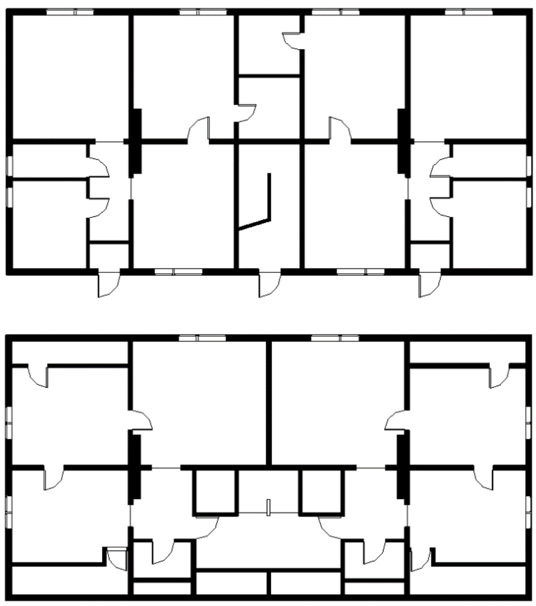
__Appendix 10 – Drawings of Puoitakvägen 5__



Bostad nr. 158 Hermelinen Omändring av bottenplan. 9/2 1966. Ritning nr. 2-127-101

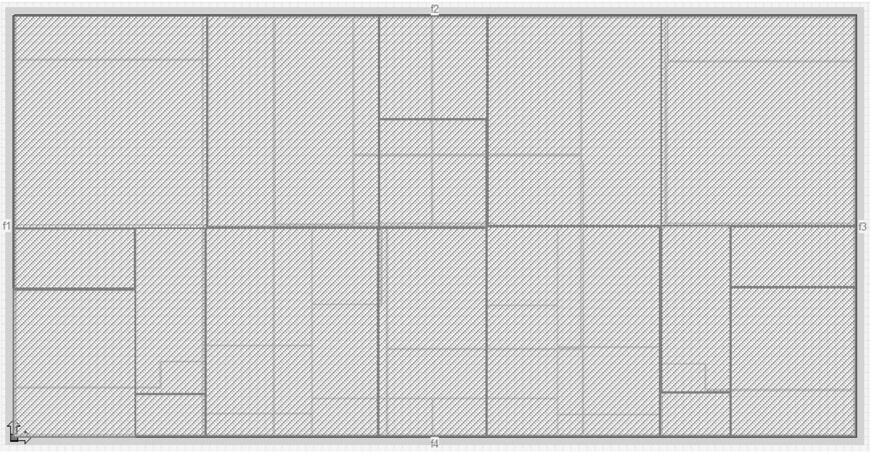
Bostad nr. 158 Hermelinen Omändring av vån. 1 tr. 9/2 1966. Ritning nr. 2-127-102

Source: Luossavaara-Kiirunavaara AB (LKAB) Archive

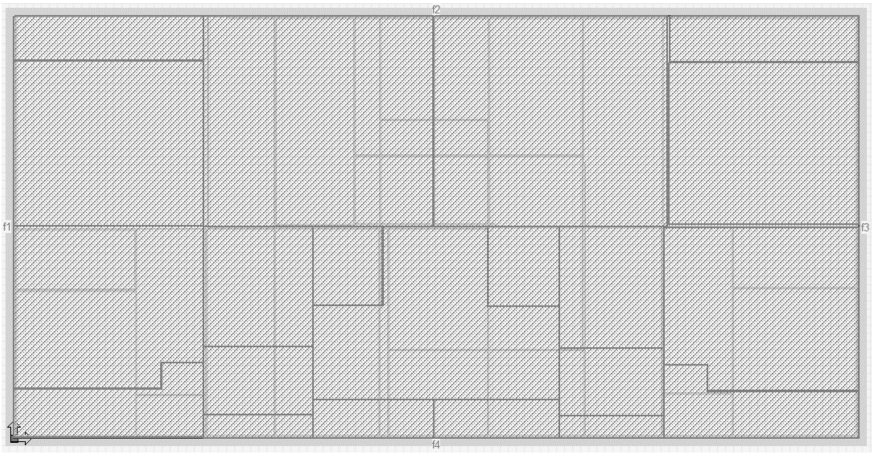


Recreation of the building using the 3D CAD software Revit Architecture 2017.

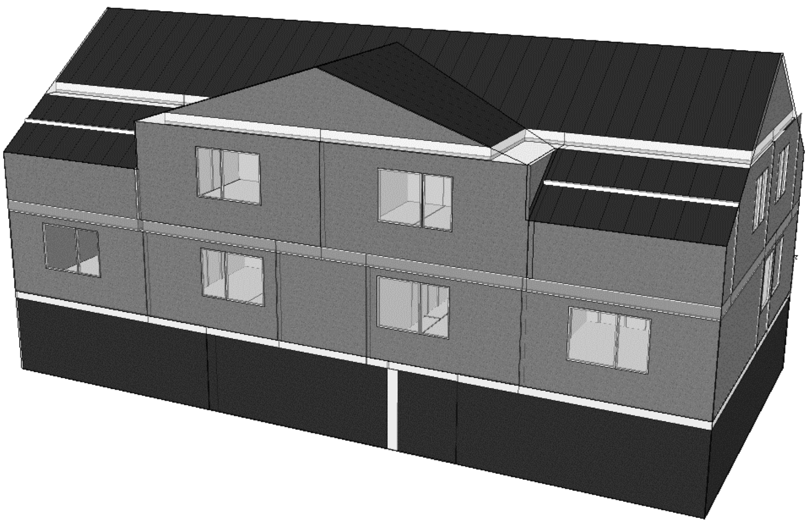
Appendix 11 – IDA ICE Base model, zone/room units and 3D-view



Entrence level of Puoitakvägen 5 - Zone/room units



Upper level of Puoitakvägen 5 - Zone/room units



3D-view of the IDA ICE base model

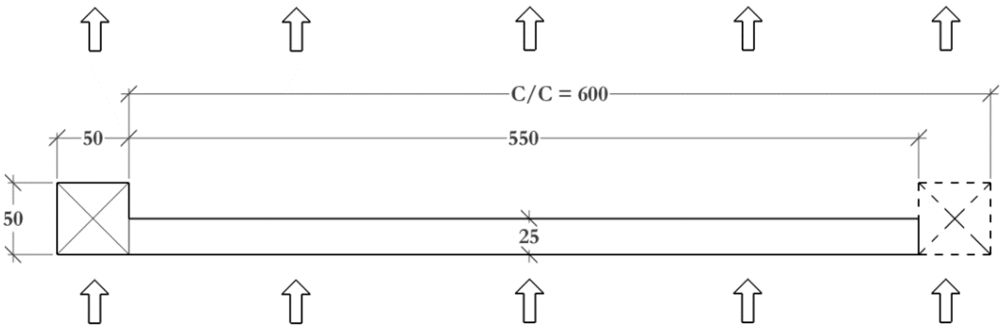
Appendix 12 – Validation of zone/room temperature

Zone/room	*Min. temp (°C)*	*Max. temp (°C)*	*Zone/room*	*Min temp (°C)*	*Max temp (°C)*
VARDSAGSRUM 1	20,9	32,3	SOVRUM 6	21	31,4
SOVRUM 2	21	32,4	TOMRUM 1	0,9	26,1
BAD 1	21	45	FÖRRÅD 1	20,9	24,8
SOVRUM 1	21	34,6	FÖRRÅD 2	20,9	24,8
KÖK 1	21	34,3	BAD 3	21	33,7
HALL 1	21	32,3	BAD 4	21	34
ENTRÉ 1	21	30,1	TRAPPHUS 2	21	27,1
TRAPPHUS 1	21	27,1	KLK 3	21	28,1
KLK 2	20,9	26,2	HALL 3	21	31,3
KLK 1	21	27,1	KLK 4	21	28
KÖK 2	21	34,4	HALL 4	21	31
SOVRUM 3	21	33,4	GARD 4	21	26,7
VARDAGSRUM 2	20,9	32,5	KÖK 4	21	32,3
HALL 2	21	30,8	TOMRUM 2	0,9	26,2
BAD 2	21	42,5	GARD 3	20,9	26
SOVRUM 4	21	30,7	VIND	-15,1	25,6
ENTRÉ 2	21	30	KÄLLARE FÖRRÅD	-1,6	15,4
SOVRUM 5	21	32,9	KÄLLARE TV+TRK	0	18,4
GARD 1	20,9	25,8	KÄLLARE VVS	-0,7	16,6
VARDAGSRUM 3	21	32,6	KÄLLARE KORR.	-0,5	16,4
VARDAGSRUM 4	21	32,7	KÄLLARE MAT	-1	16,4
KÖK 3	21	34,2	KÄLLARE SKORS 2	-2,2	16,5
GARD 2	21	26,7	KÄLLARE SKORS 1	-2,3	16,4

Controller setpoints have been defined for the air temperature in individual zones. The water radiators supply heat until the air temperature has reached 21 °C. Maximal temperatures are reached during the summer months, under the influence of warm outdoor air infiltrating the construction and solar radiation, which naturally reaches its maximal intensity during the summer months.

Appendix 13 – Manual calculations of U-values

50 mm studs and 25 mm insulation, the void has negligible effect on the thermal resistance of the construction. The layer is a component of the attic floor.



The heat-flux flows through the materials in the direction of the arrows. A one-dimensional heat-flux and stationary conditions have been assumed.

Material properties

Material	*Thermal conductivity, λ (W/mK)*	*Density, ρ (kg/m³)*	*p, part per unit length*	*Specific heat capacity (J/kgK)*
Wood	0.14	500	50/600	2 300
Mineral wool	0.036	20	550/600	750

Calculation of thermal resistance (λ-method)

$$\mathrm{R_{wood}} = \frac{\mathrm{d}}{\lambda_{wood}} = \frac{0.05\ m}{0.14\ W/mK},\ R_{mineral\ wool} = \frac{d}{\lambda_{mineral\ wool}} = \frac{0.025\ m}{0.036\ W/mK}$$

$$U_{wood} = \frac{1}{R} = 2.8\ \mathrm{W/m^2K}, U_{mineral\ wool} = \frac{1}{R} = 1.44\ \mathrm{W/m^2K}$$

$$U_{total} = p_{wood} \cdot U_{wood} + p_{mineral\ wool} \cdot U_{mineral\ wool} = 1.553\ \mathrm{W/m^2K}$$

$$\mathrm{R_{total}} = \frac{1}{U_{total}} = 0.644\ m^2K/W$$

Equivalent material properties for a uniform material (thermal conductivity, density and specific heat)

$$0.644\frac{m^2K}{W} = \frac{0.05\ m}{\lambda} \Rightarrow \lambda = 0.078\ W/mK$$

$$\rho_{total} = 8.3\ \% \cdot 500 + 91.7\ \% \cdot 20 = 59.84\ kg/m^3$$

$$Specific\ heat\ (total) = 8.3\ \% \cdot 2300 + 91.7\ \% \cdot 750 = 878.65\ J/kgK$$

These values have been used in the IDA ICE model for a composite layer of the attic floor. The same method has been used to calculate similar construction elements.

Appendix 14 – Statistics from SCB (Statistics Sweden)

Genomsnittligt antal personer per hushåll efter region, boendeform, lägenhetstyp och år

2523 Gällivare

flerbostadshus, bostadsrätt och hyresrätt (2017)

2 rum och kök: 1,3
3 rum och kök: 1,8

Lägenhetstyp:
Lägenhetstyp 2: Antal rum oavsett om det finns kök/kokvrå/kokskåp eller inte.

Senaste uppdatering:
20180419 09:30

Källa:
Statistiska centralbyrån (SCB)

Kontaktperson:
Lovisa Sköld, Statistiska centralbyrån (SCB)
Telefon: +46 010-479 64 74
Fax: +46
e-post: lovisa.skold@scb.se
Karin Rosén Karlsson, Statistiska centralbyrån (SCB)
Telefon: +46 010-479 69 98
Fax: +46
e-post: karin.rosen@scb.se

Referenstid:
31 december

Officiell statistik

Databas:
Statistikdatabasen

Intern referenskod:
0000025U

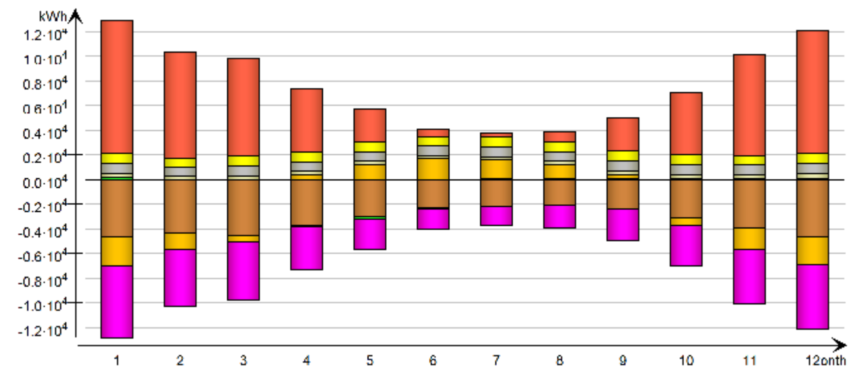
Appendix 15 – Results of energy performance analysis, Base case

EQUA SIMULATION TECHNOLOGY GROUP		**Energy for whole building**	
Project		**Building**	
		Model floor area	432.0 m^2
Customer		Model volume	1753.7 m^3
Created by		Model ground area	217.7 m^2
Location	Koskullskulle (Climate data: Kiruna)	Model envelope area	905.7 m^2
Climate file	SWE_KIRUNA_020440(IW2)	Window/Envelope	4.2 %
Case	BASE_MODEL_180925_BAS	Average U-value	0.9828 W/(m^2 K)
Simulated	2018-09-25 12:40:34	Envelope area per Volume	0.5164 m^2/m^3

All zones

kWh (sensible only)

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occupants	Equipment	Lighting	Local heating units	Local cooling units	Net losses
1	-4670.4	163.5	-2313.3	0.0	-5847.6	326.6	805.1	808.5	10724.0	0.0	0.0
2	-4313.8	-12.6	-1349.8	0.0	-4697.7	293.3	725.8	733.1	8619.8	0.0	0.0
3	-4563.2	-11.2	-547.8	0.0	-4718.0	317.6	793.8	811.9	7914.0	0.0	0.0
4	-3769.4	-46.7	356.1	0.0	-3574.0	311.1	793.7	784.0	5142.5	0.0	0.0
5	-3025.9	-211.9	1177.8	0.0	-2512.3	293.3	793.7	808.8	2676.4	0.0	0.0
6	-2329.5	-109.9	1676.8	0.0	-1624.7	239.3	771.0	782.1	594.8	0.0	0.0
7	-2172.3	74.8	1525.5	0.0	-1602.2	233.5	816.3	807.2	312.4	0.0	0.0
8	-2106.8	15.5	1170.7	0.0	-1765.2	261.7	793.8	808.8	818.8	0.0	0.0
9	-2443.2	73.9	334.7	0.0	-2516.3	298.1	782.3	783.1	2683.8	0.0	0.0
10	-3120.1	57.3	-571.0	0.0	-3296.0	317.7	805.0	812.2	4991.5	0.0	0.0
11	-3947.5	82.8	-1729.3	0.0	-4455.9	310.0	771.1	780.9	8184.4	0.0	0.0
12	-4638.8	107.1	-2224.3	0.0	-5227.5	330.5	816.5	807.9	10024.5	0.0	0.0
Total	-41101.0	182.4	-2493.9	0.0	-41837.3	3532.7	9468.1	9528.5	62687.1	0.0	0.0
During heating (7259.0 h)	-25068.7	-11594.5	-8402.3	0.0	-32052.7	2915.0	5673.8	5805.9	62691.3	0.0	0.0
During cooling (777.0 h)	-1050.2	-4347.1	4030.6	0.0	-2046.6	342.4	1759.4	1321.0	0.0	0.0	0.0
Rest of time	-14982.1	16124.0	1877.8	0.0	-7738.0	275.3	2034.9	2401.6	-4.2	0.0	0.0



Envelope transmission

kWh

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-1876.9	-1613.6	-176.8	-2417.3	-304.6	-698.8
2	-1819.4	-1328.4	-352.3	-2067.9	-258.1	-555.7
3	-1952.4	-1329.1	-465.0	-2143.7	-260.3	-556.5
4	-1621.1	-975.2	-555.8	-1733.6	-196.9	-420.2
5	-1309.2	-603.4	-696.6	-1369.3	-122.6	-294.1
6	-987.8	-337.3	-757.6	-1055.0	-62.2	-184.5
7	-906.1	-348.7	-677.8	-1010.4	-57.5	-182.2
8	-860.2	-450.8	-509.0	-992.3	-82.1	-204.7
9	-997.4	-704.2	-310.1	-1186.7	-132.7	-298.9
10	-1308.7	-959.7	-278.8	-1479.8	-181.1	-391.6
11	-1733.4	-1290.7	-152.0	-1918.4	-241.5	-529.9
12	-2065.9	-1505.7	-166.3	-2223.5	-280.8	-620.3
Total	-17438.6	-11446.6	-5098.0	-19597.9	-2180.5	-4937.5
During heating	-15115.6	-4109.4	0.0	-16653.8	-2146.4	-3697.2
During cooling	-872.3	65.8	0.0	-1790.9	-12.0	-231.9
Rest of time	-1450.7	-7403.0	-5098.0	-1153.2	-22.1	-1008.4

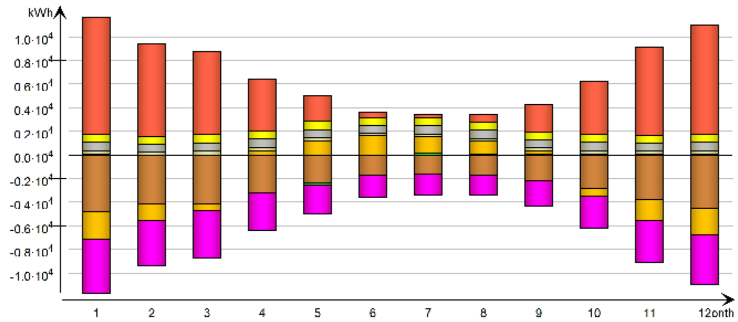
Appendix 16 – Results of energy performance analysis, light refurbishment package

EQUA SIMULATION TECHNOLOGY GROUP		**Energy for whole building**	
Project		**Building**	
		Model floor area	432.0 m²
Customer		Model volume	1473.5 m³
Created by		Model ground area	219.8 m²
Location	Koskullskulle (Climate data: Kiruna)	Model envelope area	826.6 m²
Climate file	SWE_KIRUNA_020440(IW2)	Window/Envelope	4.6 %
Case	BASE_MODEL_180913_P_FLYTT	Average U-value	0.9934 W/(m² K)
Simulated	2018-09-30 15:00:46	Envelope area per Volume	0.5609 m²/m³

All zones

kWh (sensible only)

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occupants	Equipment	Lighting	Local heating units	Local cooling units	Net losses
1	-4783.3	28.4	-2323.3	0.0	-4567.9	323.8	715.7	677.8	9925.5	0.0	0.0
2	-4099.7	-21.9	-1361.1	0.0	-3878.3	290.3	645.1	615.4	7808.4	0.0	0.0
3	-4152.9	-3.7	-563.4	0.0	-4013.3	314.1	705.6	680.7	7029.9	0.0	0.0
4	-3231.3	-16.4	338.7	0.0	-3181.1	307.4	705.6	657.5	4416.8	0.0	0.0
5	-2376.6	-161.8	1146.2	0.0	-2443.6	286.2	705.5	678.1	2165.9	0.0	0.0
6	-1676.1	-57.9	1602.4	0.0	-1838.8	223.8	685.3	655.7	405.1	0.0	0.0
7	-1606.6	113.1	1440.1	0.0	-1779.5	213.2	725.6	677.0	212.4	0.0	0.0
8	-1683.7	29.4	1113.1	0.0	-1737.8	250.4	705.6	678.1	642.3	0.0	0.0
9	-2170.8	43.8	317.2	0.0	-2135.7	293.9	695.4	657.3	2295.8	0.0	0.0
10	-2869.4	19.4	-582.1	0.0	-2726.5	315.5	715.7	679.1	4445.5	0.0	0.0
11	-3809.2	20.8	-1739.2	0.0	-3593.3	307.4	685.3	655.5	7469.8	0.0	0.0
12	-4469.0	34.0	-2235.4	0.0	-4229.4	327.3	725.6	676.8	9166.4	0.0	0.0
Total	-36928.8	27.2	-2846.8	0.0	-36125.1	3453.2	8416.1	7989.0	55983.8	0.0	0.0
During heating (6857.0 h)	-24809.1	-4522.2	-9005.7	0.0	-31412.1	2777.2	5429.7	5522.6	55982.8	0.0	0.0
During cooling (1194.0 h)	-1537.9	-4180.2	4569.2	0.0	-2872.2	408.2	2014.1	1607.4	0.0	0.0	0.0
Rest of time	-10581.8	8729.6	1589.7	0.0	-1840.8	267.8	972.3	859.0	1.0	0.0	0.0



Envelope transmission

kWh

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-2364.4	-1268.0	-144.2	-2426.9	-305.5	-701.3
2	-2011.9	-1043.3	-212.9	-2078.7	-259.1	-572.7
3	-1987.2	-1044.5	-279.8	-2158.7	-261.4	-579.8
4	-1522.2	-764.8	-304.9	-1751.1	-198.1	-441.2
5	-1121.6	-471.1	-345.4	-1400.7	-124.3	-314.1
6	-761.2	-264.1	-375.8	-1128.9	-68.2	-206.9
7	-707.8	-280.5	-349.2	-1095.7	-66.0	-203.1
8	-755.9	-360.4	-265.2	-1048.8	-86.1	-216.1
9	-1001.7	-556.6	-175.9	-1204.6	-133.5	-303.2
10	-1374.7	-756.0	-156.0	-1490.0	-181.9	-400.8
11	-1875.2	-1014.7	-132.5	-1927.7	-242.4	-544.0
12	-2210.3	-1182.7	-153.7	-2234.8	-281.8	-640.7
Total	-17694.1	-9006.9	-2895.5	-19946.7	-2208.3	-5124.0
During heating	-14969.3	-4070.5	0.0	-16254.0	-2136.7	-3632.5
During cooling	-1215.8	20.4	0.0	-2448.8	-29.8	-312.7
Rest of time	-1509.0	-4956.8	-2895.5	-1243.9	-41.8	-1178.8

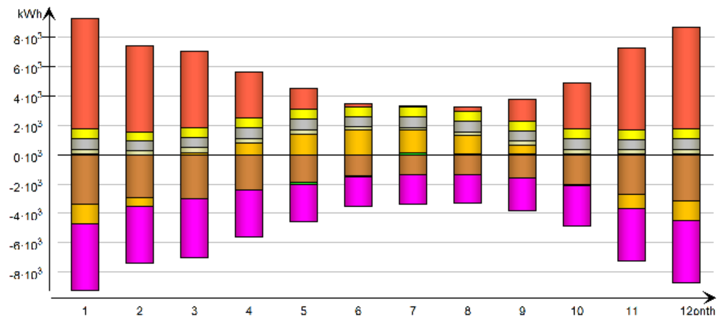
Appendix 17 – Results of energy performance analysis, moderate refurbishment package

EQUA SIMULATION TECHNOLOGY GROUP		**Energy for whole building**	
Project		**Building**	
		Model floor area	432.0 m²
Customer		Model volume	1473.5 m³
Created by		Model ground area	219.8 m²
Location	Koskullskulle (Climate data: Kiruna)	Model envelope area	826.6 m²
Climate file	SWE_KIRUNA_020440(IW2)	Window/Envelope	4.6 %
Case	BASE_MODEL_180930_MODERATE	Average U-value	0.8863 W/(m² K)
Simulated	2018-09-30 16:34:23	Envelope area per Volume	0.5609 m²/m³

All zones

kWh (sensible only)

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occupants	Equipment	Lighting	Local heating units	Local cooling units	Net losses
1	-3381.4	19.4	-1351.4	0.0	-4566.6	318.0	715.8	679.1	7563.8	0.0	0.0
2	-2948.1	-8.9	-592.3	0.0	-3877.8	285.3	645.1	615.2	5879.4	0.0	0.0
3	-3007.3	-5.2	138.9	0.0	-4019.2	308.7	705.6	680.2	5195.3	0.0	0.0
4	-2387.9	-18.4	817.0	0.0	-3198.5	301.0	705.5	656.0	3123.4	0.0	0.0
5	-1850.6	-168.3	1417.6	0.0	-2500.3	273.0	705.6	678.3	1444.8	0.0	0.0
6	-1431.6	-67.8	1714.2	0.0	-1991.3	199.6	685.3	655.2	236.1	0.0	0.0
7	-1387.4	106.1	1548.0	0.0	-1964.6	182.0	725.5	676.8	108.6	0.0	0.0
8	-1378.0	47.3	1253.3	0.0	-1888.8	227.4	705.5	678.3	352.1	0.0	0.0
9	-1602.6	49.2	622.3	0.0	-2187.9	282.2	695.5	657.8	1479.8	0.0	0.0
10	-2058.5	15.0	-77.4	0.0	-2734.8	310.9	715.4	677.0	3149.4	0.0	0.0
11	-2692.0	17.9	-978.0	0.0	-3594.2	302.6	685.3	656.5	5599.1	0.0	0.0
12	-3155.0	26.5	-1333.5	0.0	-4230.7	321.8	725.8	679.9	6961.0	0.0	0.0
Total	-27280.3	12.6	3178.8	0.0	-36754.8	3312.4	8416.0	7990.3	41093.0	0.0	0.0
During heating (6453.0 h)	-17547.3	-1701.7	-3870.8	0.0	-30190.3	2530.9	4689.9	4963.7	41091.9	0.0	0.0
During cooling (1602.0 h)	-1875.7	-4462.8	5491.2	0.0	-4367.2	506.5	2611.8	2103.3	0.0	0.0	0.0
Rest of time	-7857.3	6177.1	1558.4	0.0	-2197.3	275.0	1114.3	923.3	1.1	0.0	0.0



Envelope transmission

kWh

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-1681.5	-698.8	-148.9	-1445.0	-149.1	-702.8
2	-1450.5	-580.3	-216.3	-1236.7	-126.6	-574.4
3	-1438.9	-575.2	-283.3	-1289.8	-127.7	-582.2
4	-1115.0	-422.6	-308.5	-1053.3	-96.9	-445.0
5	-851.7	-263.1	-351.7	-859.9	-61.9	-322.1
6	-627.5	-148.7	-392.1	-727.4	-37.4	-226.0
7	-593.3	-163.1	-365.9	-718.8	-37.6	-227.6
8	-609.1	-210.3	-276.0	-681.6	-46.0	-236.5
9	-736.4	-310.7	-178.2	-740.8	-65.8	-311.5
10	-988.6	-419.4	-158.1	-891.6	-88.9	-403.7
11	-1330.2	-561.8	-135.9	-1147.6	-118.2	-545.8
12	-1566.9	-650.1	-157.9	-1332.9	-137.7	-642.3
Total	-12989.6	-5004.2	-2972.8	-12125.3	-1093.7	-5219.8
During heating	-10339.3	-2688.1	0.0	-9150.0	-1021.1	-3499.6
During cooling	-1202.9	-150.8	0.0	-2106.2	-39.0	-482.6
Rest of time	-1447.4	-2165.3	-2972.8	-869.1	-33.6	-1237.6

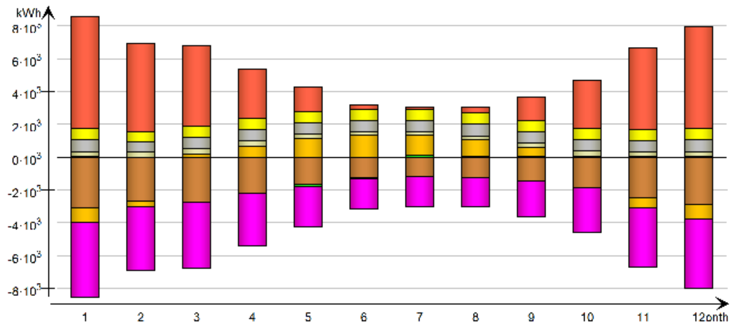
Appendix 18 – Results of energy performance analysis, heavy refurbishment package

EQUA SIMULATION TECHNOLOGY GROUP		Energy for whole building	
Project		**Building**	
		Model floor area	432.0 m²
Customer		Model volume	1473.5 m³
Created by		Model ground area	219.8 m²
Location	Koskullskulle (Climate data: Kiruna)	Model envelope area	826.6 m²
Climate file	SWE_KIRUNA_020440(IW2)	Window/Envelope	4.6 %
Case	BASE_MODEL_180913_P_FLYTT	Average U-value	0.8272 W/(m² K)
Simulated	2018-09-30 16:16:38	Envelope area per Volume	0.5609 m²/m³

All zones

kWh (sensible only)

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occupants	Equipment	Lighting	Local heating units	Local cooling units	Net losses
1	-3074.5	21.3	-885.9	0.0	-4569.0	315.6	715.7	679.4	6794.4	0.0	0.0
2	-2688.3	-9.5	-338.7	0.0	-3880.2	283.5	645.1	615.2	5370.9	0.0	0.0
3	-2750.7	-2.9	207.8	0.0	-4016.3	307.6	705.5	679.6	4866.3	0.0	0.0
4	-2181.8	-17.1	688.2	0.0	-3187.4	301.9	705.5	656.8	3031.8	0.0	0.0
5	-1675.6	-128.6	1118.5	0.0	-2457.7	279.6	705.6	678.1	1479.7	0.0	0.0
6	-1249.2	-58.8	1345.2	0.0	-1869.1	218.7	685.3	655.2	272.2	0.0	0.0
7	-1204.5	85.1	1222.8	0.0	-1838.1	205.4	725.6	676.8	122.8	0.0	0.0
8	-1223.1	32.8	997.4	0.0	-1801.0	238.2	705.5	678.6	369.0	0.0	0.0
9	-1462.0	36.5	523.5	0.0	-2163.4	283.5	695.5	658.6	1424.3	0.0	0.0
10	-1885.8	13.4	13.7	0.0	-2735.2	309.3	715.4	678.1	2888.0	0.0	0.0
11	-2450.6	16.7	-634.1	0.0	-3596.7	300.6	685.3	657.0	5019.2	0.0	0.0
12	-2867.1	25.3	-883.9	0.0	-4231.9	319.5	725.8	678.9	6229.3	0.0	0.0
Total	-24713.2	14.2	3374.5	0.0	-36346.0	3363.4	8415.8	7992.1	37867.9	0.0	0.0
During heating (6714.0 h)	-13879.6	-4079.0	-1542.6	0.0	-30628.5	2566.7	4614.0	5047.7	37868.1	0.0	0.0
During cooling (1311.0 h)	-1104.2	-3969.5	3613.2	0.0	-3495.3	482.3	2544.8	1934.9	0.0	0.0	0.0
Rest of time	-9729.4	8062.7	1303.9	0.0	-2222.2	314.4	1257.0	1009.5	-0.2	0.0	0.0



Envelope transmission

kWh

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-1072.2	-995.7	-151.8	-955.9	-149.5	-705.3
2	-943.7	-823.4	-217.7	-817.5	-126.9	-576.5
3	-937.8	-817.9	-283.2	-851.6	-128.0	-583.7
4	-733.7	-599.2	-307.0	-692.6	-97.1	-444.7
5	-576.0	-373.6	-346.5	-555.7	-61.8	-317.6
6	-414.8	-211.1	-376.5	-447.7	-35.5	-211.3
7	-374.9	-228.2	-355.1	-442.8	-35.4	-210.9
8	-390.7	-290.4	-271.2	-429.2	-45.5	-225.3
9	-472.2	-435.6	-179.4	-484.6	-66.1	-308.8
10	-637.6	-593.5	-160.6	-591.4	-89.2	-404.8
11	-845.9	-799.4	-138.9	-760.7	-118.6	-547.9
12	-993.6	-929.8	-160.8	-883.4	-138.0	-644.8
Total	-8393.2	-7097.9	-2948.7	-7913.2	-1091.5	-5181.5
During heating	-6529.8	-2765.4	0.0	-6145.7	-1027.2	-3557.5
During cooling	-613.5	-73.4	0.0	-1152.2	-28.8	-389.0
Rest of time	-1249.9	-4259.1	-2948.7	-615.3	-35.5	-1235.0