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IMPACTS OF AN UPGRADE OF TECHNICAL SYSTEMS ON GREEN BUILDING CERTIFICATION IN AN APARTMENT BUILDING

Examiners: Professor, D. Sc. (Tech.) Risto Soukka
Development Manager, M. Sc. (Tech.) Olli Nummelin

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT
School of Energy Systems
Ympäristötekniikan koulutusohjelma
Sustainability Science and Solutions

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Teknisten järjestelmien parannuksen vaikutukset ympäristösertifiointiin asuinkerrostalossa

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139 sivua, 16 taulukkoa, 22 kuvaa ja 10 liitettä

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Hakusanat: ympäristösertifikaatti, tekniset järjestelmät, talotekniikka, korjausrakentaminen, asuinkerrostalo

Tämän diplomityön tarkoituksena on selvittää, miten asuinkerrostalon teknisten järjestelmien parannus vaikuttaa ympäristösertifikaatin saamiseen. Koska olemassa olevien rakennusten ympäristövaikutusten vähentäminen on yhä tärkeämpää, työssä tutkitaan Suomessa vuosina 1976–2002 rakennettuja kerrostaloja. Tämän yhtenäisen rakennuskannan tyypillisinä ongelmina ovat riittämätön tuloilmamäärä ja ilmanvaihdon suuret lämpöhäviöt. Tutkimusten mukaan talotekniikkaan liittyvät korjaustoimenpiteet ovat kannattavimpia. Näiden toimenpiteiden vaikutukset tyypillisessä kerrostalossa approksimoidaan sertifikaattien vaatimusten perusteella arvioiden ja laskelmien avulla. Teknisiin järjestelmiin liittyvien pisteiden painotus on varmimmin suurin LEED O+M -ympäristöluokituksessa (Operations + Maintenance) (41 %) ja RTS-ympäristöluokituksessa (36 %). Kun arvioidaan kannattavimpien energiaa säästävien toimenpiteiden vaikutuksia näissä rakennuksissa, poistoilma- tai maalämpöpumpun asentamisen vaikutus on noin 20 % kokonaispisteistä LEED O+M –luokituksessa, kun taas Joutsenmerkissä ja RTS-luokituksessa tutkittujen toimenpiteiden vaikutukset jäävät vähäisiksi. Toimenpiteiden vaikutukset arvioidaan myös tyypilliselle kerrostalolle tapaustutkimuksena. Poistoilmalämpöpumpun, aurinkopaneelien ja LED-valaistuksen asentaminen tuo kerrostalolle 24 LEED O+M -pistettä lisää verrattuna toimenpiteitä edeltävään arvioon ja noin 13 pistettä melko tiukassa RTS-arvioinnissa, kattaen huomattavan osan 110 kokonaispisteestä. Tulosten mukaan teknisten järjestelmien parannuksella voi olla merkittäviä vaikutuksia sertifiointipisteisiin. Sopiva sertifikaatti ja toimenpiteiden vaikutukset riippuvat remontin laajuudesta. Rakennusvaippaan liittyvien toimenpiteiden ja ilmastointijärjestelmän parantamisen myötä sopivien sertifikaattien määrä ja saavutettava pistemäärä kasvaisivat ja esivalmistuksen hyödyt tulisivat paremmin esille.

ABSTRACT

Lappeenranta–Lahti University of Technology LUT
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Impacts of an upgrade of technical systems on green building certification in an apartment building

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139 pages, 16 tables, 22 figures, 10 appendices

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Keywords: green building certification, technical systems, building systems, renovation, apartment building

The aim of this thesis is to examine how a building system renovation can affect receiving a green building certification in an apartment building. Because of the importance of reducing the environmental impacts of existing buildings, the fairly homogeneous group of Finnish apartment buildings built during 1976-2002 is studied. The main problems of the buildings are related to insufficient comfortable supply air flow and ventilation heat losses. The most feasible renovation measures according to studies focus on building systems. Therefore, the impacts of executing these measures in a typical building are estimated with the help of certification criteria requirements by doing estimations and using suitable data in calculations when possible. LEED Operations + Maintenance (O+M) and RTS Green Leadership Tool (GLT) have the highest confirmed weightings related to building systems, 41 % and 36 %, respectively. When estimating the impacts of the most feasible energy-saving measures in the buildings, installing an exhaust air heat pump (EAHP) or a ground source heat pump has a 20 % impact on LEED O+M scores, while the impact of studied measures in Nordic Ecolabel and RTS GLT is minor. Impacts of a renovation are assessed for a typical building as a case study, and installing an EAHP, solar panels and LED lighting give the building approximately 24 more points in LEED O+M compared to an assessment before the renovation and 13 points in rather stringent RTS GLT assessment, covering a notable share of total 110 points. The results show that energy-saving building system measures can have a significant impact on certification points. The applicable certification and the impacts of the renovation depend on the scope of the renovation. Including envelope measures and improving the ventilation system would not only broaden the selection of suitable certifications but also bring out the impacts of prefabrication better and increase the certification point scores, while the renovation costs would increase.

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In Helsinki 10 August 2019

Nelli Melolinna

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LIST OF SYMBOLS

A	Heated area of the building	[m^2]
C	Coefficient for energy source	[-]
COP	coefficient of performance	[-]
E	Energy consumption	[kWh]
E-value	E-value of the building	[kWh/m^2a]
P	power	[W]
T	temperature	[K]
U	thermal transmittance	[W/m^2K]
V	volume	[m^3], [l]

Subscripts

net	net area

Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BAS	Building Automation Systems
BRE	Building Research & Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CEO	Chief Executive Officer
CHP	Combined Heat and Power
CSR	Corporate Social Responsibility
DCV	Demand Controlled Ventilation
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council)
DHW	Domestic Hot Water
EAHP	Exhaust Air Heat Pump
EED	Energy Efficiency Directive (2012/27/EU)
EPBD	Energy Performance of Buildings Directive (2010/31/EU)
ETS	Emission Trading System
EU	European Union

FIGBC	Green Building Council of Finland
GHG	Greenhouse Gas
GSHP	Ground-Source Heat Pump
GWP	Global Warming Potential
HQE	Haute Qualité Environnementale (High Environmental Quality)
HVAC	Heating, ventilation and air conditioning
LCC	Life Cycle Costs
LED	Light-Emitting Diode
LEED	Leadership in Energy and Environmental Design
MEP	Mechanical, electrical and plumbing
ODP	Ozone Depletion Potential
PPD	Predicted Percentage of Dissatisfied
PV	Photovoltaic
RTS GLT	Rakennustietosäätiö Green Leadership Tool
RTS	Rakennustietosäätiö (The Finnish Building Information Foundation)
SCOP	Seasonal Coefficient of Performance
UK	United Kingdom
USA	United States of America
USGBC	United States Green Building Council
VAT	Value Added Tax
VAV	Variable Air Volume

Chemical compounds

CFCs	Chlorofluorocarbons
CO_2	Carbon dioxide
HCFCs	Hydrochlorofluorocarbons
HCs	Hydrocarbons
HFCs	Hydrofluorocarbons
PCBs	Polychlorinated biphenyls

1 INTRODUCTION

1.1 Background and scope

There is an increasing need to save energy and reduce emissions in every industry as the consequences of climate change are gaining more and more awareness. Nations worldwide try to tackle the issue by finding ways to lower their energy consumption and especially, their emissions. For example, EU has set targets for its member states' energy consumption, emission production, renewable energy share and energy efficiency. EU has target values both in its 2020 and 2030 climate and energy frameworks and has even presented a strategy to become climate-neutral by 2050 (European Commission 2018). Finland, as a member state of EU, has received targets from the EU and has also set own ones for the year 2030, as can be seen in the following figure.

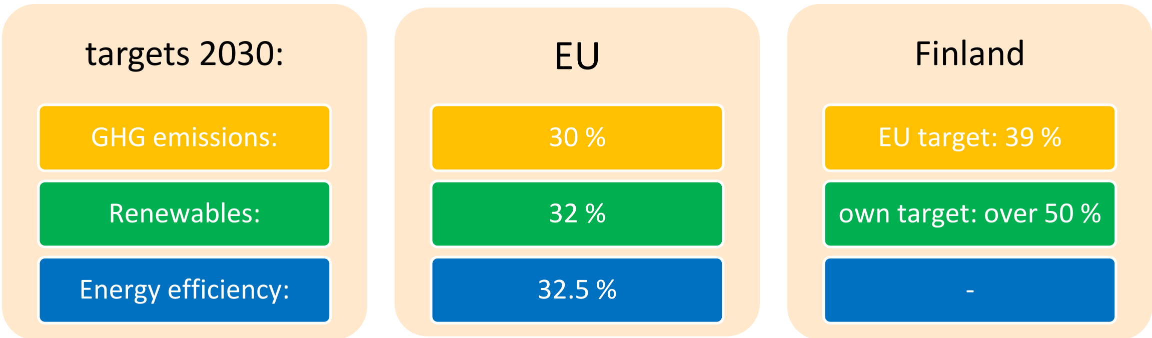

Figure 1. The main climate & energy targets in the EU and Finland for the year 2030: reduction of greenhouse gas (GHG) emissions compared to the year 2005, share of renewables in total energy consumption and increase in energy efficiency compared to 1990 levels. NB: The shown targets for reduction in GHG emissions are only for industries outside of the EU emission trading system, so-called non-ETS sectors. No target for energy efficiency in Finland specifically is set. (Directive 2018/842/EU 2018; Directive 2018/2001/EU 2018; European Commission a; Finnish Ministry of Economic Affairs and Employment 2018, 25-27.)

Buildings cause approximately 40 % of the energy use and 36 % of the emissions in the EU (European Commission b). The total environmental impacts of buildings in the US were estimated by Levin (1997) and they are consistent throughout the world (Levin 1997).

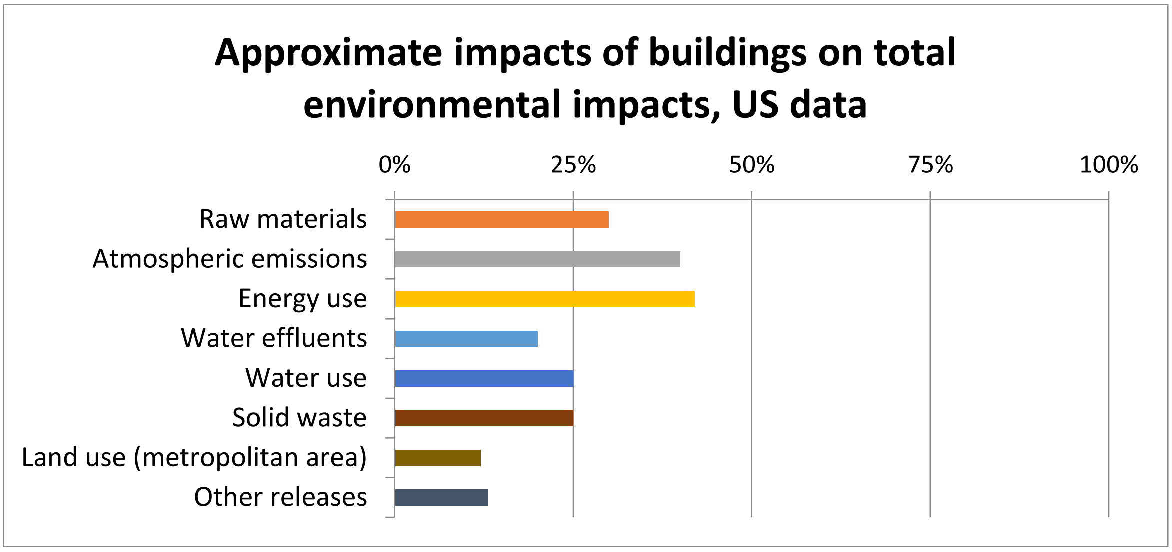

Figure 2. Estimation of impacts of buildings in the US, generally applicable also globally. (Levin 1997.)

As shown in figure 2, the resource use and emissions caused by buildings are also globally significant and these global values are very similar to above-mentioned impacts in the EU. Based on these figures, the building sector is an important sector for both EU and Finland in achieving their targets. EU has sustainable buildings as a key target area in its circular economy policy and has created e.g. a reporting framework for them (European Commission 2019). EU's directives Energy Performance of Buildings (EPBD) and Energy Efficiency Directive (EED) improve the energy efficiency of buildings in all member states. Based on EPBD the energy efficiency requirements in the building codes in the member states have been tightened, and the amending directive is aimed at further accelerating cost-effective renovation in existing buildings from 2018 on. However, EPBD also requires all new buildings to be nearly zero-energy buildings by 31 December 2020 which will greatly reduce the energy use of new buildings. When taking into account that 75 % of the building stock in the EU is energy-inefficient and the building stock is old in general, the efficiency improvement potential in these existing buildings is significant and existing buildings need to be a focus area when aiming at lowering energy use and emissions in the EU area and energy renovation possibilities need to be assessed. (European Commission b.) New buildings are relatively easy to be made energy-efficient by stricter building codes, and therefore, more attention needs to be put on the existing building stock. In 2011, is was even estimated that the energy use in the buildings existing then will form 80 % of the total energy used in buildings in most industrialized countries in

2050 (IEA 2011, 5). Subsequently, the focus is expected to shift more towards making existing buildings environmentally-friendly by e.g. retrofits for example in the US (Yudelson 2015).

Space heating and domestic hot water heating cause approximately 79 % (2240 TWh) of the energy consumption in EU households (European Commission c) and 83 % (56 GWh) in Finnish households, when heating of saunas is not taken into account (Statistics Finland 2018a, 4). In the EU, only 18 % of final energy used in households, excluding electricity, was produced by renewables in 2017 (Eurostat 2019). Most countries in EU, including Finland, have certainly room for improvement in this aspect. Therefore, cost-effective ways to improve building systems and add renewable heating energy production to households need to be researched.

There are several megatrends transform the building industry. Some of them are more universal, some more specifically related to building sector. Sweden's National Board of Housing, Building and Planning estimates the megatrends towards 2025 to be changing climate and globalized, urban and digitalized world (Boverket 2012). A Finnish futurologist mentioned five megatrends in construction industry in 2010: climate change and change in energy systems, change in demographics, globalization, digitalization and rise of experience economy (FIGBC 2010). These, among a few others, were mentioned to be the megatrends towards 2020 and beyond by an American green building expert (Yudelson 2015), a Finnish building market foresight company Forenom (Pajakkala 2017, 4), Buildings Performance Institute Europe (De Groote & Lefever 2016, 12-13) and in professional US articles (Koroluk 2016; Burgess 2014), for example. A report by nearly 160 experts analyzing the current state of Finnish built environment listed the current megatrends in Finland to be urbanization, aging population, sustainable development, diminishing resources as well as technological development and digitalization (ROTI 2017, 64-66). Many experts seem to agree on the upcoming trends in building industry. As a conclusion, especially themes related to sustainability, digitalization, urbanization and diminishing resources need to be researched as thoroughly as possible, and often, because these concepts are constantly evolving. This study is going to address nearly all these megatrends, as they are largely interconnected as well. The three pillars of sustainability are considered throughout this entire thesis when environmental, social and economic impacts are assessed; digitalization is an important part of the solutions in the case building; urbanization and diminishing resources are addressed by focusing on apartment buildings, which are mostly used in urban areas and by considering prefabrication, which can reduce material, energy and time consumption (Chang et al. 2018).

An apartment building (Finnish: “asuinkerrostalo”) or a block of flats is used in this thesis by its Finnish definition: building with at least three apartments, of which at least two are on top of each other (Statistics Finland 2019). The scope of this Master’s thesis is chosen to include only the apartment buildings built during the period 1976-2002. This is done because of the similar structural and HVAC solutions used in this part of the building stock as the Finnish building code did not require substantial changes during this time (D 1048/2017, 9-11). Apartment buildings in general form 21 % of the floor area and account for 25 % of the residential heating energy use in Finland (Statistics Finland 2018b; Statistics Finland 2018c) and have, therefore, a significant potential for energy savings. There are several methods for improving energy efficiency and the share of renewable energy use in apartment buildings, but this study focuses mostly on building system renovations. Building systems can be defined to include the technical systems in a building in contrast to the building envelope; at least the electrical, HVAC, energy management, security, lighting and data communications systems in a building are included. Additionally, this thesis aims at providing a glance at prefabricated building system solutions, as they can be seen as components of above-mentioned megatrends as well.

One method to measure and reduce the negative impacts of buildings is promoting the use of green building certifications, also known as green building ratings, as they can motivate to make sustainable choices in buildings. These certifications are becoming more common for apartment buildings, and moreover, for existing apartment buildings and apartment buildings under renovation. In Sweden, this practice is already fairly common and researched topic – almost 1000 apartment buildings are certified in Sweden (SGBC 2019a), while in Finland only a few apartment buildings have received a green building certification (Kauppinen 2019a). SGBC (Sweden Green Building Council) estimates that all buildings need to be environmentally certified in the future and states that the building industry should be very proactive with certifying (TIB 2018). However, green building rating systems for existing or renovated apartment buildings is not a deeply researched topic in Sweden either, and therefore, they need to be examined more closely because of the above-mentioned increase of renovating existing buildings.

This thesis is written for the Finland-based company Caverion and it is also related to an EU-funded project. Caverion provides technical solutions for buildings and industries in Europe, and its services are related to design, building, operation and maintenance (Caverion 2019a).

1.2 Objectives and structure of the study

The main objective of this study is to find out how an upgrade of building systems can affect receiving a green building certification in an apartment building. In order to get best results, the follow-up research questions addressed in this thesis are:

- Which building system renovation options are optimal?
- Which green building certification schemes are most suitable for Finnish apartment buildings under building system renovation and how suitable are they?

The main research question is aimed to be answered by both estimating the impacts of building system renovation measures on green building certification criteria and by estimating certification points for a case building. Furthermore, the subject of prefabrication and its possible impacts on green building certification is discussed.

The following three chapters of this thesis present the concepts addressed in this study. The first of these chapters presents the building stock that is included in this study. The next theory chapter presents the principles of some of the most common and most feasible building system renovation options, focusing on an exhaust air heat pump. A relevant theme considering the case building and building industry in general, prefabrication, is also discussed shortly in this chapter. The last theory chapter presents the most significant green building certification systems that can be used for apartment buildings during operation and maintenance or renovation, as well as some key information about certificating.

The fifth chapter of this study presents the research methods used to answer the research questions. The next chapter aims at finding the criteria in certification systems that can be affected by a building system renovation, and assesses the possible impacts of certain renovation measures. The seventh chapter presents the case building used in this study located in Kerava, Southern Finland, and presents the suitable renovation measures. The chapter also estimates the impacts of the planned building system renovation on possibilities to receive a certification, by assessing certification points for the building both before and after the renovation. The feasibility and suitability of such certifications is assessed in both chapters. Finally, conclusions and summary are presented.

2 APARTMENT BUILDINGS AND THEIR TECHNICAL SYSTEMS

The scope of this study includes only the existing apartment buildings in Finland built approximately during 1976-2002. This part of the building stock is chosen in order to have a consistent yet substantial group of buildings – during this time, the changes in energy-related regulations in the Finnish building code were relatively small (D 1048/2017, 9-11). This chapter often refers to buildings built during 1975-2000, as many of the references describe the qualities of buildings from this period. These descriptions are often representative of the considered period 1976-2002 as well since no significant legislative or design-related changes happened during 2000-2002.

2.1 Overview and building structures

In 2017, there were 60 644 apartment buildings in Finland in total and 1 941 000 people inhabited these buildings – 36 % of the population (Statistics Finland 2018b; Statistics Finland 2018d; Statistics Finland 2018e). The following figure presents the numbers of apartments and the total floor area in apartment buildings built during the last 100 years.

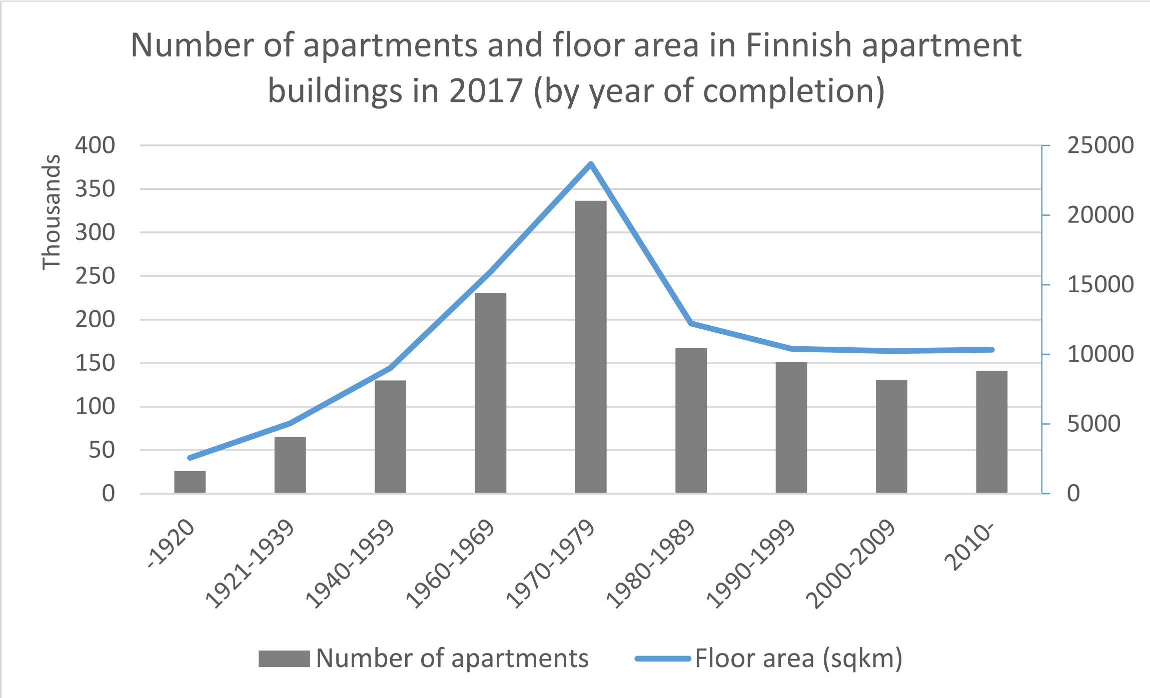

Figure 3. Number of built apartments and built floor area in Finnish apartment buildings in 2017 by year of completion. NB! 99 apartment buildings had an unknown year of completion, and they were excluded from this graph, leaving 1154 apartments and 120 km^2 out of the graph as well. (Statistics Finland 2018b; Statistics Finland 2018d.)

As can be seen in figure 3, roughly 47 % of the total existing floor area in apartment buildings is built during 1970-1999. However, during 1975-2000, which is closer to the scope of this study, building of apartment buildings reduced after the record year 1974. In total, 465 555 apartments were built in apartment buildings during this time, which is 34 % of all apartments in apartment buildings. (Neuvonen 2018, 8.) This represents a significant share of all apartments in Finnish apartment buildings.

After 1974, the focus was shifted more towards detached houses and row houses and less apartments were built in general, hence the decrease in built apartment buildings. However, the building quality was improved as a contrast to the industrial building trend and rather problematic structure design of the earlier decades. Because of the recession in the 1990s, more buildings were built with the help of government funding and the aim was to have more stories and smaller apartment areas than before. (Neuvonen 2015, 8-9, 17.)

Apartment building construction has been regulated by several different documents – construction was regulated mostly by Finnish Building Act (Rakennuslaki ja –asetus), but in the middle of the 1970s the Finnish building code was created and the Finnish Land Use and Building Act (Maankäyttö- ja rakennuslaki) came into force in the beginning of 2000. The minimum recommendations in design instructions by Finnish board of housing became more detailed during the 1970s and 1980s and were considered of the highest quality in the apartment building industry. However, instructions from the building developer, often greatly determined by construction phase costs, had the biggest effect on building. Not until the 1990s were the life cycle costs clearly taken into account during the planning phase. (Neuvonen 2015, 11-13.)

The most common structure for apartment buildings during the period in question was a bookshelf frame, and especially prefabricated concrete walls were used, which resulted to fewer bearing walls. The most common wall structures were concrete sandwich panels, which had a varying width of mineral wool (120-150 mm), depending on the current building code. (Neuvonen 2015, 38-41.) The façades became more varied after the end of the 1970s: brick, ceramic plate and coloured concrete were used instead of plain concrete, and balconies were not only supported by walls but also columns. However, the concrete walls were often seamed with sealing compound that contained harmful PCB substances until 1979 or lead until 1989. (Neuvonen 2015, 15, 44.) When it comes to roofs, flat roofs were commonly used until the end of the 1970s, after which lean-to roofs and gable roofs became much more common. Flat roofs turned out to cause several problems with rainwater draining. (Neuvonen 2006, 224-225.) From the middle of the 1970s, one more layer of glass was added to the double-paned windows, but PCBs were still used in the sealing compounds until 1979. (Neuvonen 2015, 49.) Elevators were required to be built also in apartment buildings with three floors during the 1990s. The floor height was also changed in 1995, as the minimum changed from 2.80 m to 3.00 m. (Neuvonen 2015, 67.)

The Finnish building code has been updated several times, but between 1976-2002 the updates were less substantial. The first regulations for building insulation came into force in 1976, and values for thermal transmittance, ventilation or air tightness were almost constant during the period. (A 1048/2017, 9-11.) The typical values for the period are shown in the table below, containing also heating and ventilation-related values.

Table 1. Typical values for Finnish apartment buildings built in 1976-2002. (Hirvonen et al. 2018, 5.)

U (thermal transmittance), external wall [W/m^{2}K]	0.34
U, floor [W/m^{2}K]	0.38
U, roof [W/m^{2}K]	0.26
U, doors [W/m^{2}K]	1.4
U, windows [W/m^{2}K]	1.7
Air tightness 50 Pa [1/h]	1.0
Air change rate [1/h]	0.5
Specific fan power in ventilation [kW/m^3/s]	1.5

2.2 Heating systems

Most apartment buildings included in the scope use district heating as their heating system, while some have boilers using e.g. oil or biomass. Almost all buildings have a waterborne heating system. Before the heating need calculations in the Finnish building code in 1986, the heating need was dimensioned according to instructions from the Finnish association of heat and water technology (Lämpö- ja vesijohtoteknillinen yhdistys). The plant room (also called heat distribution center in Finnish) in an apartment building is usually located in the basement of the building, close to the communal district heat pipes. Tube heat exchangers were commonly installed in the 1970s, but more efficient and much smaller plate heat exchangers came into use in the 1980s, which originally had problems with durability, but were greatly improved during the next decade. Typically the outside temperature, temperature of the incoming and outgoing water and water pressure were measured near the plant room. (Neuvonen 2015, 68-70.)

About 80 % of district heat in Finland is produced by CHP (Combined Heat and Power) (Finnish Energy 2006, 27). District heat is usually produced fairly locally, which is why the used fuels vary depending on the area (Finnish Energy). The average fuel distribution in Finland is shown in the following figure.

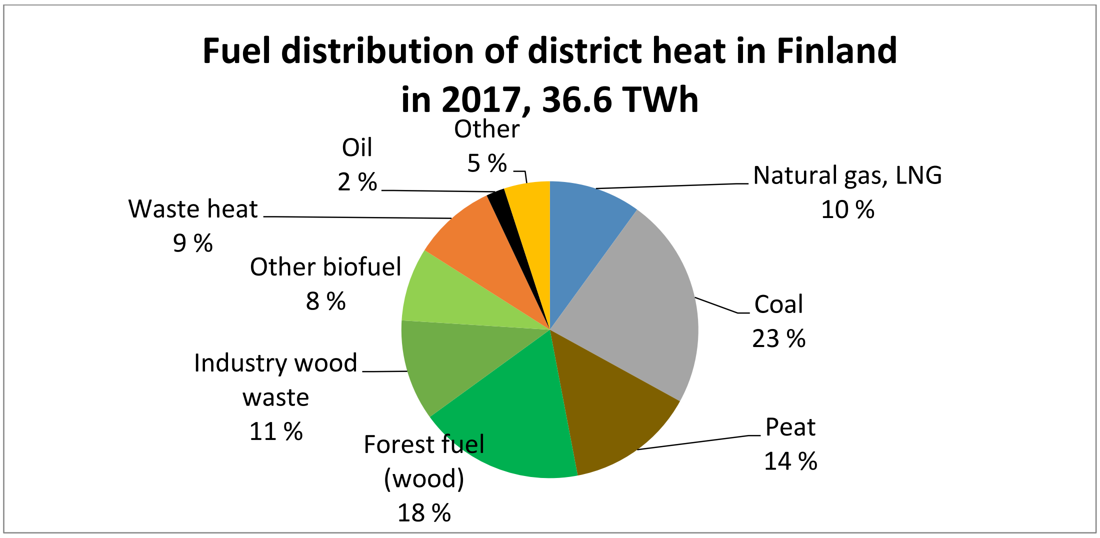

Figure 4. Fuel distribution of delivered district heat. (Finnish Energy 2018, 5.)

Figure 4 shows that the most used fuels are coal and the use of peat is substantial as well, making the production quite carbon-intensive. However, the use of fossil fuels has decreased from the previous year (Finnish Energy 2018, 4-5).

The water from the district heating plant is transferred via insulated underground pipes in the temperature of 65-115 °C and transferred further from the plant room in a temperature depending on the outside temperature. Heat is transferred to the building's heating water and domestic hot water (DHW) typically in two separate heat exchangers, after which the water temperature should be approximately 25-50 °C. The water distribution system in the building is initially adjusted and balanced so, that the right temperature is reached in each room – if else, some spaces are colder and some warmer than needed. The radiators are typically radially connected (two-pipe system) by steel pipes, excluding some apartment buildings from the 1970s. (Neuvonen 2015, 68-73.) The water is received to the top of the radiator through a thermostatic radiator valve and exits the radiator via the blanking plug. (Korkala 2018, 53). The typical design values for radiators were 70°C/40°C, and the goal temperature indoors was set to 22 °C (Hirvonen et al. 2018, 5). The incoming and outgoing water are led to the apartment through separate pipes through intermediate floors and each apartment has several risers. Having risers in the staircase was experimented in the 1990s. The pipes were usually insulated only in the horizontal parts in the basement and the insulation material commonly contained asbestos still during the 1970s. Water-regulating thermostats were added to radiators after the 1973's energy crisis and some years later they were used for preset control, cutting off a large portion of the heat consumption. (Neuvonen 2015, 68-73.)

When it comes to building automation systems (BAS), after the energy crisis the first centralized automation systems for the heating, ventilation and electronic systems in several buildings were created, yet the system was still analogue and each signal required an own cable. During the 1980's, the systems became more efficient and digital, and in the 1990's their use became a lot more common because of the mobile internet-based solutions in BAS. (Sähkötieto ry. 2018, 13-17.)

2.3 Ventilation, water and sewage systems

The most commonly used ventilation system in these buildings was mechanical exhaust ventilation, although natural ventilation was never forbidden in the regulations. Mechanical supply and exhaust ventilation systems were built starting from the 1980s, but after the recession of the 1990s, mechanical supply ventilation was generally considered "too expensive". Typically the apartments on top of each other have a shared exhaust air duct. The blower in the mechanical ventilation system was operating at full power at all times, except for nights, a certain time during the day and when the outside temperature fell below -10 °C. As the system created a negative pressure in the apartments, replacement air entered either through leakages (until the late 1980s) or supply air vents. Some problems occurred when using both the leakages and vents. For example, sounds and smells were easily transferred between the apartments and bedrooms often had inadequate ventilation. In the case of leakages, leaked air was unfiltered and even water could leak in. The buildings were often built incompact, and thermal stratification made air leak from the lower apartments to the staircase and further to upper apartments, causing temperature differences in the building and bad air quality in the upper apartments. Air vents, in turn, sometimes caused drag and outside air was still mostly entering the building through leakages. Furthermore, the filters in air vents require frequent cleaning. (Neuvonen 2015, 82-86.) Because of the time-controlled ventilation in the apartment buildings and having some doors closed in the apartments, the air change rate is usually too small during the day, especially in bedrooms, where the CO_2 concentration often can be over 2000 ppm, when approximately 900 ppm is considered adequate. Therefore, these systems should be upgraded. (Virta & Pylsy 2011, 85-89.)

When it comes to centralized mechanical supply and exhaust air ventilation systems, the supply air is filtered and preheated by recovered heat from the exhaust air in the heat recovery unit, and then further led to each apartment. During colder seasons, the supply air is additionally heated by electric resistors or district heating. Each staircase has an own ventilation unit on the roof of the building. The heat recovery system usually contained a plate heat exchanger with 60% temperature efficiency. Centralized supply air system is easier to maintain without entering the apartments. In an apartment-specific system, every apartment has an own ventilation unit that the tenant is able to control. The apartment-specific ventilation system improved the indoor air quality and allowed utilization of heat recovery, but they also caused problems with noise from the system itself, positive pressure in the apartment as well as unclean supply air and fouling of the heat exchangers. (Neuvonen 2015, 86-88; Neuvonen 2009, 233.)

When looking at the water and sewage systems, their design was controlled by Finnish building code starting from 1976. Beginning from the 1990s, a relief valve was installed in apartment buildings, but in higher apartment buildings the water pressure needed to be increased. The temperature of DHW was instructed to be kept between 50-60 °C, while nowadays a temperature under 55 °C is considered to cause bacterial growth. (Neuvonen 2015, 74-75.) The vertical water ducts/pipes are usually located so that horizontal piping can be done as short as possible. Especially during the 1970s and 1980s all the vertical water and sewage pipes as well as ventilation ducts and electric wires were often placed hidden in the bathroom element. The water pipes were usually made of copper, while the vertical pipes going to apartments in the manifold system were made of polyethylene. The pipes were also insulated with mineral wool. After the energy crisis more showers were installed instead of bathtubs. (Neuvonen 2015, 75-78.) When it comes to the sewage systems, the sewage pipes coming from the bathroom equipment as well as from the kitchen were usually connected to the main sewage pipe already at the factory. The main sewage pipe continues upwards and through the roof as a vent pipe. The horizontal parts were usually built inside the concrete floors or led inside the roof of the apartment below. The sewage pipes were usually made of plastic. (Neuvonen 2015, 78-80.)

2.4 Energy consumption

The heat energy consumption per square meter reduced 10-20 % in average in these buildings when compared to apartment buildings established in the 1960s and 1970s, because of the stricter building code as a result to the energy crisis (Neuvonen 2015, 68.) The average annual heat energy consumption of apartment buildings during 1976-2002 decreased from 55 kWh/m^3 to 45 kWh/m^3 in Southern Finland. The heat energy use is approximately 10-15 % higher in Central Finland and 25-30 % higher in Northern Finland compared to Southern Finland. 20-30 % of heating energy is commonly used for heating DHW. (Virta & Pylsy 2011, 20-21.)

The heat energy balance of a typical apartment building in Finland is shown in the figure below.

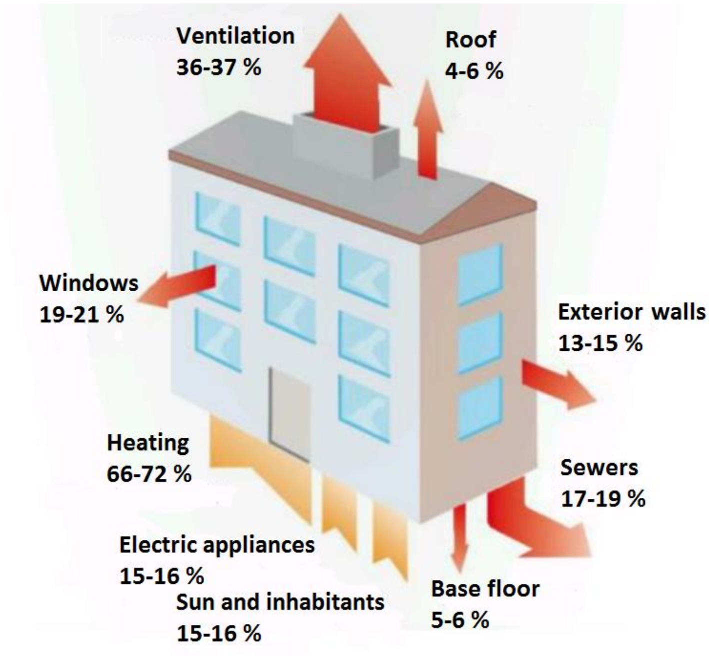

Figure 5. Heat energy balance of an apartment building built in the 1960-1980s (modified after Virta & Pylsy 2011, 19).

As can be seen in figure 5, the largest area of energy use is clearly ventilation, as there is usually no heat recovery from exhaust air.

When looking at the electricity consumption of building systems in common spaces (e.g. lighting, sauna, elevators), the average annual consumption has been rather constant in apartment buildings built between 1976-2002 – 4.2 kWh/m^3. The share of lighting is 15-30 % in these buildings. The household electricity consumption is usually paid by the tenant instead of the housing company, and the average annual consumption is about 2550 kWh in an apartment of 2-3 people. (Virta & Pylsy 2011, 22-25; Motiva 2018a.) The average water consumption in apartment buildings is commonly about 155 liters per person in a day, but it varies greatly among tenants. 40-75 % of hot water and 36 % of water in general is used for showering, making it the most significant area of water usage. (Virta & Pylsy 2011, 26-28.)

As decreasing energy consumption and emissions of buildings is becoming more and more important, attention needs to be paid to the whole life cycle of the building because of their long life. A simple illustration of a building´s life cycle is shown in the figure below.

Figure 6. Building life cycle stages. (Bionova 2017, 13.) This is a standardized version, but slightly different phase divisions occur depending on the source.

When examining life cycles of buildings as seen in figure 6, the energy consumption or carbon footprint (all emissions caused by the building, expressed as CO_2) is mostly composed by the use phase. The share of the use phase in a conventional Finnish building is about 63-75 %, while in China it is estimated to be even up to 85 %. In newer, more energy-efficient buildings the use phase impact becomes almost as low as that of construction phase and demolition phase combined. (Bionova 2017, 11-12; Finnish Ministry of Environment 2016; Peng 2016.) Consequently, it is essential to lower the energy use of existing buildings by upgrading the building systems.

In Finland, it is very common to use a weighted energy consumption value or computational energy efficiency comparison value, called E-value (kWh/m^{2}a), to demonstrate the energy consumption. The E-value determines the energy class of a building in its energy performance certificate. The value is calculated according to the following equation using computational values. (D 1048/2017, 4-22.)

$$E - value = \frac{\sum_{i=1}^{k} E_i \cdot C_i}{A_{\text{net}}} \tag{1}$$

where	*E-value*	E-value of the building	[kWh/m^{2}a]
	E_i	Annual purchased energy consumption by energy source *i*	[kWh/a]
	C_i	Coefficient for energy source *i*	[-]
	A_{net}	Net heated area of the building	[m^2]

E-value is weighted by energy sources: the coefficients *C* for energy sources are 1.2 for electricity; 0.5 for district heat; 0.28 for district cooling; 1.0 for fossil fuels and 0.5 for renewable fuels used in the building. The energy consumption can be calculated or estimated by using building-specific or building type–specific energy performance values of the building structure and of the building systems. (D 1048/2017, 4-7.) However, from 2007 until 2013 the E-value calculation did not include household electricity and the requirements were lower than now (D 1032/2008), and as each apartment building has had to present an energy performance certificate since 2008 when intending to sell an apartment (A 487/2007), most of the buildings considered here have this differently assessed E-value.

3 UPGRADING THE BUILDING SYSTEMS IN APARTMENT BUILDINGS

This chapter describes the process of an apartment building renovation briefly and presents some suitable building system renovation options for Finnish apartment buildings. The focus is on renovation options that can save energy in the building, whereas other important units like security and data communications systems are not considered as much.

3.1 Overview of the building system renovation process

The renovation process can be described in several ways. The core of the process consists of the following steps: project planning, planning, preparing the renovation, renovation and receiving the final building and granting the warranty for the renovated parts. (Kiinteistölehti 2017.) The optimal low-energy renovation process starts with deciding the desired final state of the building after the renovation. This is done by the property owner and an expert panel. After the initial condition survey, suitable repair concepts are chosen and the client decides the most suitable one. The following instructions from the Finnish Ministry of Environment can typically be used when planning a renovation to create a low-energy building. (RIL 249-2009, 195-197.)

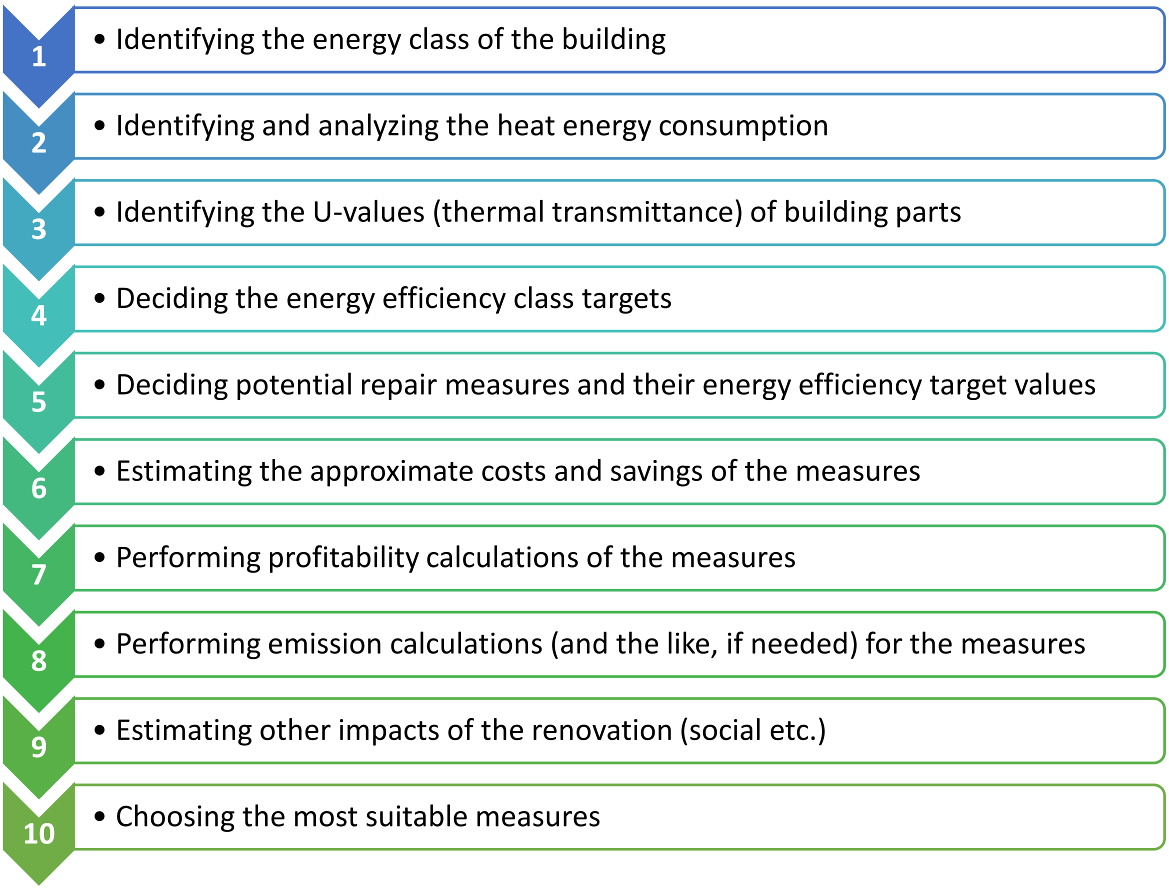

Figure 7. Recommended renovation planning process for energy-efficient buildings. (RIL 249-2009, 198-199.)

Figure 7 presents a more detailed version of the process steps in the planning phase, and the order of process steps might slightly vary from project to project. During the project planning, the main aims, repair methods, quality and scope are decided, for example. Also, the needed initial information is gathered and the costs and timetable are tentatively decided, and some energy consumption costs and life cycle costs should be calculated. This is the most important part of the renovation process as the success and feasibility of the renovation is largely decided during it. The project planning is easier to execute if the building already has a repair strategy or program. The final product of project planning is the project plan including the key information. During the planning process, the project plan is used to create detailed plans in the form of calculations, technical drawings and work plans, and more detailed choices are made. The actual renovation starts with risk assessment and the tenants should be informed about the renovation typically approximately five years before, and they should also be able to comment the plans. The renovation is usually supervised by a building engineer working for the developer, but also having the specific designers as supervisors can be a good solution. (RIL 249-2009, 199-206; Virta & Pylsy 2011, 141-153.)

The housing company often has to find additional funding for the renovation project. The most common method in Finland is to apply for a housing company loan, but it is usually important to gather funding from the tenants for a few years before the renovation. This can even be used to fund smaller renovations entirely. The tenants can also pay their exact share of the project shortly before or after the renovation. The housing company can also sell some of their properties or apply for government subsidies. The amount of subsidies available depends on the year. The possible subsidies for renovation projects in entire apartment buildings in Finland are interest subsidy loans or renovation subsidies for building elevators or making the building more accessible, adding charging stations for electric cars and/or for maintenance of built heritage, while the latter is primarily for older buildings than the buildings considered in this thesis. (Kiinteistöalan kustannus 2016; ARA 2019; Kotitalo 2019.)

The legal framework of repair construction in Finland includes the Land Use and Building Act (132/1999) and Decree of the Ministry of the Environment on Improving the Energy Efficiency of Buildings in Conjunction with Repair and Modification Works (4/13). The former regulation orders that the energy-efficiency of a building should be improved when doing alteration works that are subject to permission or changing the use of the building, when it is technically, economically and functionally feasible. The latter gives more specific orders in same circumstances and presents three alternatives for improving energy-efficiency:

1. reducing the thermal transmittance values of building parts a certain amount, or
2. reducing the final purchased energy to a certain value depending on the building type (in the case of apartment buildings, 130 kWh/m^2 at most), or
3. reducing the weighted energy consumption (E-value) to a certain percentage of the current E-value (in the case of apartment buildings, 85 % at most).

This decree also sets performance values for renovated building systems and orders a verification of the accurate operation of the building systems. Building permit is required for renovation works where the energy-efficiency of a building can be significantly changed. Therefore, these regulations need to be followed in most energy renovations. However, the requirement of building permit for certain renovation measures depends on the municipality. (Almgrén & Rinne 2013, 7-15; A 132/1999; D 4/13 2013; D 2/17 2017.)

3.2 Feasible renovation options

The main modules (or units) of energy renovations are structure units (external walls, windows, solar shading and balcony and entrance doors) and building system units (ventilation and heat recovery system, internal heat exchange and distribution system and heat energy supply and the related system). Typical renovation options for the envelope of an apartment building are changing the windows, adding external insulation to outer walls and/or adding insulation to the roof. (RIL 249-2009, 200-208.) In the case of building systems, the typical renovation options can be used to control the systems better or renew the systems completely or something in between. The renovation choices usually are related to the heating systems, water and sewage systems, ventilation systems, building automation and/or cooling. (RIL 249-2009, 221-223.) It is often feasible to combine the renovation options to reach the best and most energy-efficient outcome. A generally given piece of advice is to only perform larger energy saving measures when the building needs to be renovated anyway. This also works the other way around – when doing any renovation measures the building's energy efficiency should be improved. (Motiva 2018a.)

When choosing the optimal renovation options, life cycle costs tend to be the most important criterion. However, energy savings and even emission savings are becoming more prevalent parameters in these decisions. The feasibility of renovation measures in Finnish apartment buildings has been researched several times during the 2000s by taking both energy-efficiency and cost-effectivity into account. The best solutions for apartment buildings in all age classes in Finland were GSHPs (ground-source heat pumps), demand controlled ventilation and solar PV (photovoltaic) panels (Hirvonen et al. 2018). In all cases, building envelope measures, such as additional insulation, were not very cost-effective (Hirvonen et al. 2018, 16; Niemelä et al. 2017; Niemelä et al. 2016). However, adding low-cost roof insulation was often feasible. Furthermore, the less insulation the envelope contains (which usually correlates to an older building) the more feasible adding insulation is (Hirvonen et al. 2018, 20). According to a report made for the European Commission in 2012, when reaching the highest accepted energy consumption after renovation, the most cost-effective renovation solution for a Finnish brick apartment building from the 1960's is installing more energy-efficient windows including installing an EAHP to be used along with district heating. For a 1970's apartment building the results were similar, however these solutions were estimated to be less cost-effective. This report considered also e.g. building envelope measures, additional electric heating and heat recovery in addition to the above-mentioned, more cost-effective measures. (Saari et al. 2012, 82-107.) The newer version of this report from 2018, however, suggests that the most cost-effective renovation option for an apartment building from the 1970s is a quite extensive set of measures resulting to 281 €/m^2 costs during 30 years: changing the windows, adding insulation to the external walls and the roof and installing an EAHP. The 30-year cost estimation of the option with most building system measures (water-saving installations, EAHP and passive wastewater heat recovery, in addition to window change) was only 283 €/m^2 making it also a relatively cost-effective solution. (Airaksinen et al. 2018, 27-36, 57.) Based on these two EU reports, at least a window change was needed to reach the required level of energy-efficiency. However, by implementing even more building system renovation measures than presented in these reports might result to an acceptable cost and energy consumption level.

The studies conducted by Hirvonen et al. (2018), Niemelä et al. (2017) and Niemelä et al. (2016) aimed at finding the most optimal renovation solutions from millions of measure combinations in apartment buildings built between 1960-2002, focusing more on the scope of this thesis in terms of building age class. For large-panel apartment buildings built during 1960-1999, installing a GSHP turned out to be the best solution, followed closely by installing an EAHP or an air-to-water heat pump. Installing solar PV was cost-effective with all above-mentioned heating methods, as well as installing solar thermal collectors when using district heating. (Niemelä et al. 2016). When looking at Finnish brick apartment buildings from the 1960's, same measures proved to be the most cost-effective, and renovating the ventilation system was often too expensive alike envelope measures (Niemelä et al. 2017). However, these buildings are outside of the scope of this thesis. When looking at all apartment buildings built during 1976-2002, adding insulation to the envelope is generally only feasible in the roof and mostly only when installing a GSHP. Additionally, changing to more energy-efficient windows can be a feasible renovation measure for apartment buildings in this age class, as also concluded in the reports by Saari et al. (2012) and Airaksinen et al. (2018). The most cost-effective renovation concepts included installing a GSHP as well as wastewater heat recovery and solar PV panels. When using district heating, as most of these buildings currently do, adding mechanical supply ventilation system with heat recovery and demand controlled ventilation decreased the produced emissions significantly. Adding an EAHP to the system was also a recommendable solution. The measures resulting to the highest emission reductions were not cost-effective, which shows that compromises need to be made when choosing the measures. (Hirvonen et al. 2018, 16-22).

The above-mentioned studies found installing a GSHP, EAHP, solar thermal and solar PV as well as changing the windows to be one of the most cost-effective measures for this building age class. Based on chapter 2, the problems of these buildings are mostly related to the lack of comfortable supply air especially in living spaces, which shows the need of a mechanical supply air ventilation system, and DCV with heat recovery would be ideally added in order to reduce energy use. Unfortunately, these measures were not proven to be as cost-effective. Since the cost-effectiveness of any envelope measures is debatable in the buildings included in the scope and including these measures adds complexity, renovation options related to the building envelope are excluded in this thesis and the main focus is on building systems. There are several aspects and variables that have to be taken into account when choosing the most optimal renovation options for a certain building and the variation of recommendations in different instructions and studies is large. Hence, the considered options should not be limited to the above-mentioned combinations and the suitable renovation options should be determined based on the building properties.

3.3 Principles of common building system renovation options

The following subchapters include descriptions of the operation principles of central energy renovation measures focusing on new installations instead of simply improving the existing systems. Aspects related to building envelope are not considered. Exhaust air heat pump is studied in more detail as it is primarily considered to be used in the case building. Feasibility and suitability for hybrid heating are also briefly discussed.

There are several other building system renovation and installation options available that are not described extensively in this chapter because of their simplicity or in some cases, lower impact on energy savings or lower importance in the case building. Some of them are a part of regular maintenance. Any building systems can be equipped with newer installations of e.g. valves, filters or heat exchangers. The HVAC systems can also be adjusted to function better in the building. The water supply system can be modified to save water or thermal energy by installing relief valves or water-saving fixtures, and apartment-specific water-metering and billing can be applied. The lighting systems can be made more energy-efficient by LED lighting. New elevators and security systems can be installed as well, but these will have a smaller effect on the energy consumption in the building, but they can contribute to better safety and comfortability and therefore, give points in the certification systems.

Some of these measures result to significant energy savings in most building system renovations. For example, adjusting the heating system can save 10-15 % of heating energy and water-saving fixtures can save 15-50 % more water compared to the typical fixtures in these buildings. Some larger measures and more expensive measures include e.g. installing mechanical supply air ventilation with heat recovery, where the heating energy savings are 10-30 % and the indoor air quality is improved. (Motiva 2018a; Virta & Pylsy 2011, 92-108.)

3.3.1 Exhaust air heat pump

An exhaust air heat pump is utilizing the heat in exhaust air in mechanical exhaust ventilation systems and transfers its heat to a waterborne heating system, DHW or to supply air. (Motiva 2008, 3-5.) The following figure presents the principle of a heat pump.

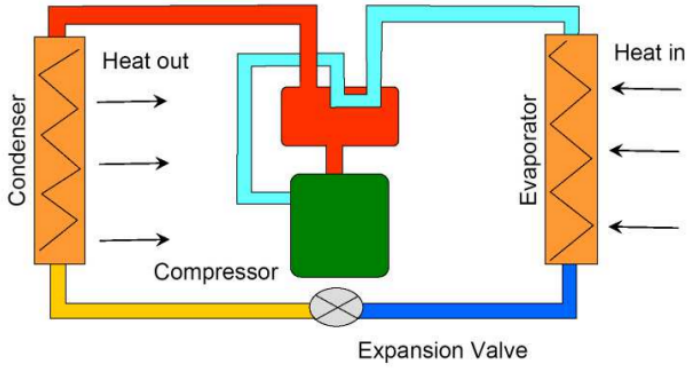

Figure 8. Principle of a heat pump based on compression and condensation of a working fluid (Zhang et al. 2014, 607).

As seen in figure 8, the heat in exhaust air (or other heat source in the case of other heat pump types) vaporizes the circulating cooling liquid in the evaporator. This steam's pressure and temperature are then increased in the heat pump's compressor before the steam is led to the condenser. The heating water or supply air to the household is also circulating in the condenser, and so the heat from the cooling liquid steam is transferred to the heating water or supply air. The condensed cooling liquid is led through an expansion valve back to the evaporator. (Motiva 2008, 3-5.)

Efficiency of a heat pump is generally measured as COP (Coefficient of Performance) or SCOP (Seasonal Coefficient of Performance) which show how many units of heat it produces per one unit of electricity. COP can be calculated according to the following equation:

$$COP = \frac{\Phi_C}{P} = \frac{T_2}{T_2 - T_1} \qquad (2)$$

where	COP	coefficient of performance	[-]
	Φ_C	thermal power of the condenser	[W]
	P	electrical power of the compressor	[W]
	T_1	temperature of exhaust air (to the heat pump)	[K]
	T_2	temperature of outlet water (from the heat pump)	[K]

COP is a momentary value, while SCOP considers the efficiency during a whole year. However, these values assume that the efficiencies of the compressor and other parts of the heat pump are 100 %, and the actual total efficiency is, therefore, lower than COP or SCOP. But the following always applies: the colder the extract air (the air leaving the EAHP) is, the more heat has been transferred to the supply air, i.e. the more effective the heat pump is – some new models produce extract air in temperature -15 °C. A common temperature for the exhaust air from an EAHP is +5 °C. (Finnish Ministry of the Environment 2017, 9-10; Perälä 2013, 30-32; Motiva 2018b; Energi- och klimatrådgivningen 2017.)

As the heat source, exhaust air, has a relatively constant temperature, the COP/power of the EAHP is constant during a year (2-3 kW). During warmer seasons the exhaust air going to the EAHP is slightly warmer. In a single-family house with low energy use, an EAHP could cover the whole heating need – however, the heat pump is usually equipped with an additional electric resistor in order to assure the sufficient heat supply in colder climates, but this electricity consumption can be reduced by producing heat inside the house by burning wood, for example. By using an exhaust air heat pump, generally about 40 % of heating costs can be saved when compared to electric heating. Additionally, an EAHP removes humid air from rooms where this is needed and some EAHP models can also be used for cooling. (Motiva 2008, 3-10; SULPU; Motiva 2018b.)

An EAHP requires at least a mechanical exhaust ventilation system, a mechanical supply ventilation system is optional. An EAHP is most affordable in a situation where the heated area is large compared to the heating need. (Motiva 2018a; Perälä 2013, 79.) In addition, an EAHP is more affordable in a building with more floors and even more affordable when installing simultaneously with new plumbing systems or roof exhaust fans. In areas with high district heating costs an EAHP is more feasible, and the EAHP should be used only for space heating in case of low district heating fees. (Juuti 2016; Virta & Pylsy 2011, 125; 26). EAHP is usually installed in the plant room, as shown in the following figure. It can also be installed in warm roof space or near the roof exhaust fan.

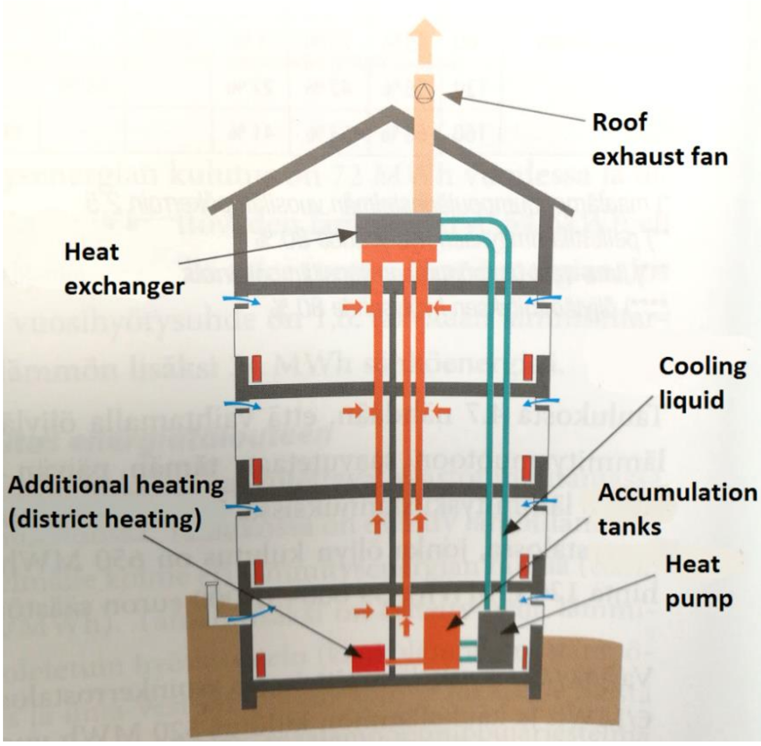

Figure 9. EAHP in an apartment building with mechanical exhaust ventilation system. Modified after (Virta & Pylsy 2011, 124).

As shown in figure 9 as well, the heat exchanger is always located next to the roof exhaust fan. The cooling liquid can be led to the heat exchanger in the staircase, outside of the building or in a suitable vertical chase. For some years ago an EAHP with a SCOP of 2 was estimated to save about 30 % of heating energy (Virta & Pylsy 2011, 124-125). However, EAHPs with better SCOP values are available, and it might be realistic to estimate that the heating energy savings are 70-80 % while the total energy savings are 45-50 % (Nummelin 2019a) when the electricity consumption rises according to equation 2.

Refrigerant options

The most common refrigerants in heat pumps used to be CFCs (chlorofluorocarbons). After their use was banned because of their ozone layer depletion potential, HCFCs (hydrochlorofluorocarbons) became more popular. Their global warming potential (GWP) is not too much lower than that of CFCs, and therefore, HCFCs were banned, too. Currently the most used coolants are HFCs (hydrofluorocarbons) that also go under the names R404a and R410a. These have a neutral effect on the ozone layer, yet they are greenhouse gases. (Perälä 2013, 46.) Consequently, also HFCs are being phased out in the EU and their use is being phased out in new air-conditioning appliances, heat pumps and commercial and industrial refrigeration appliances during 2010-2030, followed by other countries later (2014/517/EC).

The next step of refrigerants seems to be natural coolants, which include e.g. carbon dioxide CO_2 (R744) and carbon hydrates (HC) such as propane (R290). The GWP factor of HFCs is 2000, while it is only five for HCs and one for CO_2. (Perälä 2013, 46.) CO_2 stands out as the most climate-friendly option. Furthermore, it can even be captured from the air and in this way, reducing the total carbon dioxide content in the atmosphere and using a “climate-positive” coolant. However, CO_2 requires high operating pressure when used as a working substance – over 100 bar is required. This results to stricter requirements when it comes to designing and maintaining heat pumps. For example, the compressor can be smaller in size because of the elevated temperature, but usually, a two stage compressor is needed to create the elevated pressure. As a result, carbon dioxide is able to produce warmer air or water (up to +70 °C) without having a lower COP value. (Perälä 2013, 46-47.) In practice, refrigerants do not cause any harm to the environment or humans if they are handled properly and no leaks occur. Carbon dioxide is non-toxic and non-flammable, making its use even safer. (Perälä 2013, 46-47.)

3.3.2 Other renewable energy sources

Some other renewable energy sources are looked into in this chapter. The relevant installation options are ground source or air-to-water heat pump, biofuel burning, wastewater heat recovery and also solar thermal and solar PV (photovoltaic). Most of these methods are suitable for apartment buildings as hybrid energy systems.

A GHSP can be used to reduce the carbon-intensity of an apartment building’s heat consumption. However, according to some sources, it is not suitable as a secondary heating system and often not cost-effective even as a primary heating method in an apartment building that uses district heating (Virta & Pylsy 2011, 115), which is the case with most of the apartment buildings considered in this thesis. However, according to chapter 3.2, it can be cost-effective when energy and emission savings are also considered and the installation can be more affordable especially when other excavations are done in the area. Similarly as in figure 8, the ground or a water body serves as the heat source causing the refrigerant in the GSHP to evaporate and transfer heat to the heating water. The SCOP of a GSHP was typically 2.5-3.5 for eight years ago, and a GSHP is generally used to cover 80-95 % of the heating need, which adds up to approximate energy savings of 50-70 %, when electricity use increases according to equation 2 (Virta & Pylsy 2011, 115-120; Motiva 2018a.) An air-to-water heat pump is most suitable when a GSHP would require too much space in a building with electric storage heating or oil boiler. The principle is the same as shown in figure 8, and the heat is derived from outdoor air and transferred to the heating water with a SCOP between 1.4-2.7. (Virta & Pylsy 2011, 120-121; Motiva 2018b.) However, the current SCOP values are most probably higher. Both heat pumps can be used for cooling as well (Motiva 2018a).

Biofuel boilers are suitable for replacing oil boilers in apartment buildings, for example. When pellet fuel is used, the efficiency stays the same when changing from oil heating. (Virta & Pylsy 2011, 114-115.) Either active (includes a heat pump) or passive (includes a heat exchanger) wastewater heat recovery with efficiencies of approximately 70 % and 30 %, respectively, can be used in apartment buildings. As can be seen in figure 5, wastewater causes 17-19 % of the heat losses in an apartment building making the heat recovery a good building system renovation option. The heat recovery system can either be placed directly near each shower drain or more centralized in conjunction with the main sewage pipes. The closer to the actual drain inlet the heat recovery system is placed, the warmer the heat source is. (Hirvonen et al. 2018, 6-7; Oesterholt & Hofman 2014, 4-6.) It is most feasible that the heat would be recovered from the shower drain by a heat pump (Nummelin 2019a). Therefore, when considering that the system could save maximum 70 % of hot water used in the shower, the possible building-level heat energy savings are 6-16 %, when assuming showering causes 40-75 % of DHW use and that the share of heating DHW is 20-30 % of heating energy, as mentioned in chapter 2.4.

Solar thermal can be used as a secondary heating system in Finland, as the much needed heat production during the winter is low. It can well be used for DHW heating, as its demand is virtually equal during the year, and the heat can also be stored in the accumulation tank. (Korkala 2018, 57-58.) The solar thermal collectors are installed on the roof and occasionally on the walls. When looking at the liquid solar thermal systems, the evacuated tube collectors are more efficient than the flat plate collectors, as they can utilize also diffused radiation and can therefore be used also during cloudy days, but they are more expensive than flat plate collectors. In both collectors solar radiation heats up the water-glycol mixture circulating inside the tubes in the collectors, and the heated liquid is transferred to the accumulation tank in the plant room. The system is usually dimensioned to heat 50 % of the DHW, resulting to overall 12.5 % heating energy savings, while it is possible to use it for floor heating as well. The system also requires a pump and automation for controlling the system. The annual heat production is approximately 250-350 kWh/m^2 for flat plate collectors and 350-450 kWh/m^2 evacuated tube collectors. Solar heat can also be used passively without any devices, but this requires changing the building envelope in order to receive more or less solar radiation on the structures or inside the building. (Virta & Pylsy 2011, 20-21, 126-127; Motiva 2018c.) Solar PV panels include PV cells where electrons create an electric current when hit by photons in solar radiation. In Finland, a PV system with peak power of 1 kW$_p$ can produce approximately 700-1000 kWh electricity annually, covering up to nearly 2 % of typical electricity use in common spaces in a 13 000 m^3 apartment building. The produced electricity is currently easiest to use to cover some of the electricity in common spaces and not in households due to the required smart meter installation, reducing the cost-effectiveness of the installation. However, the regulations are expected to change soon allowing the use for household electricity as well. The theoretically optimal installation position for solar thermal collectors or PV panels in Finland is a 45° angle towards south, but when considering the low production during winter, the best results are achieved by having a 15° angle instead. Furthermore, on gable roofs it is most cost-effective to install the panels or collectors directly on the roof. Storing the derived thermal or electric energy is also an important aspect for consideration. (Korkala 2018, 166-169; Motiva 2018d; Motiva 2018c; Motiva 2018a; Nummelin 2019b.)

In the cases of some above-mentioned energy production methods, especially solar power, the current efficiencies are most probably higher than the mentioned values. Most of the above-mentioned methods can be used as parts of hybrid energy systems. However, hybrid systems are usually more affordable in buildings with electric heating. The different heating methods can heat the circulating liquid and further, heating water, to different temperatures creating good circumstances for combining different energy sources. For example, solar PV can be used for a heat pump’s electricity supply and solar thermal can be connected to oil boiler or district heating, both of which are common in the buildings included in the scope. Solar thermal collectors can also be used with GSHPs and biofuel boilers. (Motiva 2018c; Motiva 2018d.)

3.3.3 Building automation

Building automation systems (BAS) can be used to measure, steer and monitor all the technical systems in a building. The systems are formed by sub-distribution boards, which are connected to each other and control regulating units according to information coming from sensors. The systems often also have remote access. The performance of the technical systems can be viewed usually on a portable user terminal or a remote display terminal, and the information, especially different alarms, can be sent to end users. (Korkala 2018, 92-94.) The conventional, hierarchic system of BAS is composed by three different levels: management level for monitoring, automation level for steering and field level for measuring. However, in today’s systems there is less hierarchy as the different devices have become more independent. (Sähkötieto ry 2018, 59-61.)

In Finland, the Land Use and Building Act and the Finnish building code demand the use of such control and measurement systems that enable the energy-efficiency, healthiness and safety of the building. (Kukkonen et al. 2015, 12-16.) This sets the demand for BAS in Finnish buildings.

BAS can usually reduce the energy use in the building thus contributing to lowering the environmental impacts of the building. Costs are reduced as well, both directly in the long term and indirectly by bettering the living or working conditions. It is also beneficial to integrate the different sections of BAS, as they usually affect each other. For example, controlled solar shading affects the building’s heating or cooling demand. Furthermore, the same sensors can sometimes be used for many different controls and resources can be saved in this manner – for example, motion detectors can be used for controlling lighting, ventilation as well as intrusion detection. (Kastner et al. 2005.) For example, motion-controlled lighting in common spaces in apartment buildings saves 50-70 % of electricity for lighting, and LEDs can decrease the consumption by 60-90 % more compared to fluorescent lights or incandescent bulbs (Motiva; Rautkylä & Pasanen, 9), resulting to 5-19 % total electricity savings when households are excluded. It is important to monitor the operation of the control systems, as their malfunction can cause overconsumption of energy and loss of comfortability in buildings. Badly integrated or installed control systems can cause fluctuation in the operation of building systems. (Sähkötieto ry 2018, 226-229.)

When it comes to ventilation, sensors can be used to track the CO_2 and relative humidity levels and based on the values the ventilation system can be controlled. Especially when using variable air volume (VAV) units instead of fixed outlets, the ventilation can be precisely controlled. These units can be used for demand controlled ventilation (DCV), where the air flow is changed automatically based on e.g. the above-mentioned parameters. DCV systems are commonly used especially in rooms with largely varying occupancy rate, but their use in all spaces is becoming more common. In the case of some examined classrooms, lecture rooms and landscaped offices in Belgium, DCV saved about 50 % of fan electricity demand and approximately 40 % of ventilation heat losses. In Sweden, using demand controlled exhaust ventilation in a typical apartment building seemed to lower the heating energy demand, but the economic feasibility was questioned. (Virta & Pylsy 2011, 100-101; Kastner et al. 2005; Merema et al. 2018; Pavlovas 2004.) However, this study was done in 2004, and the automation systems have most probably improved since then.

The use of building automation systems will most probably increase each year. The systems can especially be used with controlling hybrid heating solutions, where the energy is produced by more than one energy source, which is becoming more common in construction. BAS can even use weather forecasts and electricity prices for optimizing the energy use. (Kukkonen et al. 2015, 18-19; Motiva 2018e.) The next steps for BAS are most probably even more intelligent and integrated systems as well as cloud-based services (Sähkötieto ry 2018, 17).

3.4 Prefabrication of building systems

Prefabrication has an increasing importance in the building industry and is also relevant in the case building used in this study, which is why it is discussed here. Prefabrication as a term is used differently in different countries and many other terms are used to describe prefabrication. The term can be defined, for example, in the following way: prefabrication, off-site fabrication and offsite production are used interchangeably to mean elements intended for building construction that are produced offsite to a greater degree of finish and assembled onsite. The term modular is also used to mean prefabricated solutions, and it means assembling the final product of standardized parts with simplified physical interfaces. (Aitchison 2018, 15-16; Peltokorpi et al. 2018, 3.) The conventional method for assembling parts and structures at building sites is by building everything on-site. The prefabrication level of parts varies, thus, there are varying definitions for a prefabricated product or part and most produced structures are more likely built by a combination of prefabrication and on-site production.

In many studies, prefabrication is proven to increase the productivity and decrease material use in construction projects. Waste reduction levels in construction phase can be over 50 % and the buildings generally have lower life-cycle emissions compared to conventional buildings. The reductions in overall environmental impacts and energy consumption of the project can be significant. In the US, 65-80 % of industry actors reported that prefabrication decreased costs, waste and/or project schedules. (Peltokorpi et al. 2018, 1; Jaillon et al. 2009; Teng et al. 2018; Cao et al. 2015; McGraw-Hill Construction 2011, 1). However, it is probable that a moderate level of on-site production should be retained for best results (Lu et al. 2018). The studies present also many possible downsides of high prefabrication level, including higher costs, longer design times and inflexibility (Zhang et al. 2018), but the consensus on prefabrication is positive.

The pros and cons are similar when it comes to prefabrication of building systems. The largest savings concern the project schedule. Modular systems are also easier to maintain and repair. (Ahti-Virtanen 2019.) For example, there are modular panels integrating almost all needed building systems in a room or workstation (Caverion 2019b), needed HVAC systems in an apartment (Ahti-Virtanen 2019) or completely finished bathrooms (Junnonen 2012). Such solutions are easier, faster and more tenant-friendly to install and maintain during renovation and operation. Generally, they are also of more consistent quality. However, more accurate measurements are needed in renovation projects in which prefabrication is applied. (Ahti-Virtanen 2019; Junnonen 2012). Costs can be saved through prefabrication of building systems if the project is planned well from the start. Additionally, the overall benefits of prefabrication are more prevalent when more time and precision is used on planning and the prefabrication process is repeated in order to become accustomed to the principles. (Peltokorpi et al. 2018, 9.)

According to US Green Building Council, prefabrication and modularization would improve not only construction efficiency, but also employee safety, maintenance efficiency and safety, which shows that prefabrication has an impact on green building certifications at least through these aspects (USGBC 2019a). 31 % of hundreds of industry actors estimate that the use of prefabrication helps a project to receive points in LEED certification (McGraw-Hill Construction 2011, 39). Furthermore, almost all of nearly 40 surveyed industry actors in a conference paper think that LEED should also separately award points for prefabrication mostly because of the most probable waste reductions (Adams et al. 2014).

4 GREEN BUILDING CERTIFICATIONS FOR EXISTING APARTMENT BUILDINGS

Green building certificates are used to measure and compare the environmental performance of buildings and to ensure the sustainability of the building by using an external evaluator (FIGBC 2018a, 3). There are several green building rating systems available globally. They are all different from each other and are therefore suitable for different types of buildings. Moreover, there are certification systems adapted for different kinds of projects: new construction, renovations, existing buildings and even for regional and infrastructure projects (Kauppinen 2017, 3). However, not all systems are used globally or are even suitable for all countries, and the interest in certifying buildings varies - by the end of 2018, only 180 buildings were certified in Finland (Lampela 2018), while for example in Sweden, almost 1200 buildings are currently certified (SGBC 2019a). However, over 1500 buildings have received a national certification in Finland, but this system (PromisE) is no longer in use. (Karhu 2015, 25; FIGBC a.)

This chapter will focus on certification systems available in Finland. However, as green building certifications are not widely used in Finland, examples from other countries are mentioned as well in order to find certification schemes adoptable to Finland. The certification systems that are usable for existing apartment buildings and apartment buildings under renovation are presented in the next chapters. There are also some emerging certifications focusing more on the wellbeing of the tenants (e.g. WELL, Fitwell) (FIGBC 2018a, 7) but these are excluded from this thesis. The following chapters present each of the different certification schemes and present the suitable certification schemes.

The terms related to green building rating systems are used in a confusing manner at times. In this thesis, the rating systems are also called certification systems. Firstly, the user would choose the applicable certification system (LEED, for example) and the suitable scheme or adaptation based on the project type, such as New Construction or In Use. Most of the certification systems have different certification levels, such as Gold or Platinum. These certification levels can be reached by attaining points in different categories and sub-categories, which are both called as criteria in this thesis. The points will then be added up and the final score determines the certification level. The systems often also have minimum requirements or prerequisites that need to be filled in order to get the certification. However, the preferred terms do vary from one certification system to another, for example, BREEAM calls the attained points as credits, while LEED calls the sub-categories/criteria (such as Rainwater management) as credits. (BRE 2019a; Roberts 2014.) The main aim of term usage in this thesis is clarity.

4.1 Introduction to green building certification systems

The compared certification systems are the international systems LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method) and the national RTS GLT (Rakennustietosäätiö Green Leadership Tool) and Miljöbyggnad, as well as the Nordic Ecolabel (Nordic Swan). Miljöbyggnad is not used in Finland, but as it is very commonly used in Sweden especially for apartment buildings (SGBC 2019a) and Sweden is similar to Finland in terms of e.g. weather conditions, building regulations and processes, also Miljöbyggnad is taken into consideration.

LEED (Leadership in Energy and Environmental Design) is created by the United States Green Building Council (USGBC) and it is the most widely used green building certification system in the world – it is available in 165 countries. The criteria are the same in all countries and the certified buildings are, therefore, easy to be compared with each other, yet the criteria are not always well applicable in all countries, as they are based on American practices (USGBC 2019b; FIGBC a.) BREEAM is the oldest green building certification system (BRE 2019b). The criteria are adapted to European conditions and can further be made even more applicable for certain countries. Consequently, BREEAM is the most widely used green building certification system in Europe, and it is used in 81 countries altogether. (FIGBC a; BRE 2019b.)

RTS GLT is a Finnish certification system based on European standards and Finnish building practices. RTS GLT focuses especially on good indoor air quality. RTS GLT replaced a national system called PromisE in 2017. PromisE was used in Finland from the beginning of 2000s to 2017, and it was used to certify 1500 buildings. However, it is no longer in use, as it was not updated. RTS GLT was developed based on feedback from the industry and it is mostly targeted for public construction projects. (FIGBC a; Sariola 2019; Rantanen et al. 2017, 8; Lampela 2018.) Nordic Swan is a widely-known Nordic eco-label which use for certifying buildings is on the rise. Its criteria are same in all Nordic countries and they are more focused on material choices and used chemical compounds in comparison to other certification systems. (FIGBC a; Lampela 2018.) Miljöbyggnad is a Swedish certification system only applicable in Sweden, and it is adapted to Swedish regulations and standards. (SGBC 2015, 5-8.)

The following table shows a brief comparison of the above-mentioned certification systems.

Table 2. Comparison of selected green building certifications. ([1]FIGBC 2018a; [2]USGBC 2019b; [3]BRE 2019a; [4]RTS a; [5]SGBC 2019a; [6]Holopainen 2019; [7]Wahlström 2018; [8] Ecolabelling Sweden a; [9]BRE Global 2019.) (Logos: Katz 2014; FIGBC 2018b; Sariola 2018; Byggherrarna 2018; Ecolabelling Finland a.)

Logo	LEED	BREEAM	RTS	Nordic Swan Ecolabel	Miljöbyggnad
Establishment year and country	1998, US [1]	1990, UK [1]	2017, Finland [1]	2005, Nordic countries [1]	2009, Sweden [7]
Points leading to rating levels (if applicable for all certificates)	40-49 p.: Certified 50-59 p.: Silver 60-79 p.: Gold 80+ p.: Platinum [2]	Pass Good Very Good Excellent Outstanding [3]	25-39 p.: 1 star 40-54 p.: 2 stars 55-69 p.: 3 stars 70-84 p.: 4 stars 85+ p.: 5 stars [4]	Certified	Bronze Silver Gold [7]
Certified in Finland	114 [1]	234 [9] [*]	- [1]	5 [6]	-
Certified in Sweden	249 [5]	702 [9] [*]	-	Hundreds [8]	1352 [5]

[*] The numbers of BREEAM certifications include different parts of assessment in the In Use scheme, making the actual number of certified numbers approximately one third of the shown number. For example, the actual number of BREEAM certified buildings in Finland is 62 [1].

The numbers of certifications shown in table 2 can vary slightly depending on the source. However, it is obvious that LEED, BREEAM and Miljöbyggnad stand out as the most used certifications in Finland and Sweden. Furthermore, the figure below shows how popular different certifications are in Nordic countries for new buildings. It has to be noted, however, that Finland has approximately 1500 buildings certified with PromisE and Sweden has a corresponding number of buildings certified with Miljöbyggnad and half as many certified with Nordic Ecolabel (FIGBC a; SGBC 2019a; Ecolabelling Sweden a).

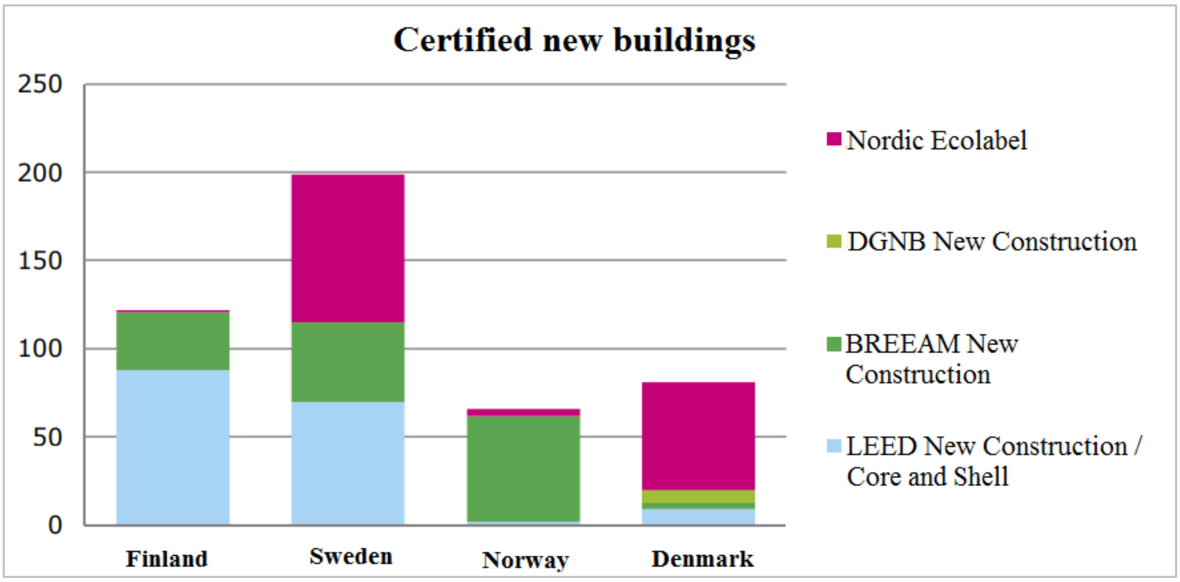

Figure 10. Number of certified new buildings in the Nordic countries in 2017, selected certifications (modified after Rantanen et al. 2017, 8).

As can be seen in figure 10, Sweden has the most certified buildings in the Nordic countries, while Finland has the largest number of LEED certifications. Furthermore, the following figure shows the portion of certified new and existing buildings in companies in the construction industry in the Nordics in 2017, and it also shows how these different actors presume the share of certifications to change.

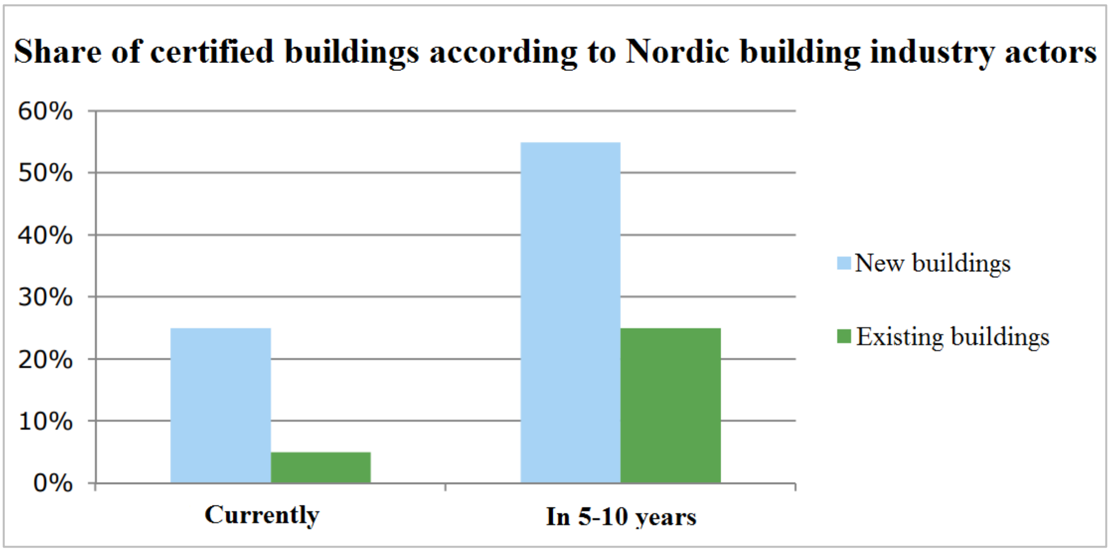

Figure 11. Share of certified buildings in the portfolio or in new buildings being certified according to Nordic construction industry actors (property owners, investors, contractors, tenants, service providers) in 2017 and in 5-10 years, as median value. (Modified after Rantanen et al. 2017, 12-18.)

When looking at certifications for existing buildings in figure 11, it can be seen that very few existing buildings are certified at the moment (2017), but the actors predict the number to be 500 % larger in 5-10 years, while the number of certified new buildings is assumed to be doubled. However, nearly half of the respondents were from Finland and thus, the result does not equally represent all Nordic countries. Nevertheless, almost 400 industry professionals contributed to this result and it is very likely that the share of certified existing buildings will rise. (Ramboll 2017, 18-19.)

The following figure presents the weighting shares of category groups from four certification systems, grouped mostly by the certification authorities. They cannot be directly compared to each other as the shown categories include different criteria depending on the certifications. The figure presents the weighting of maximum points for repair construction and/or residential buildings. The weighting of obligatory criteria is decided to be the median point value of the criteria in LEED, corresponding 2 points. Since Nordic Ecolabel only has obligatory criteria for repair construction, one criterion is chosen to correspond one point.

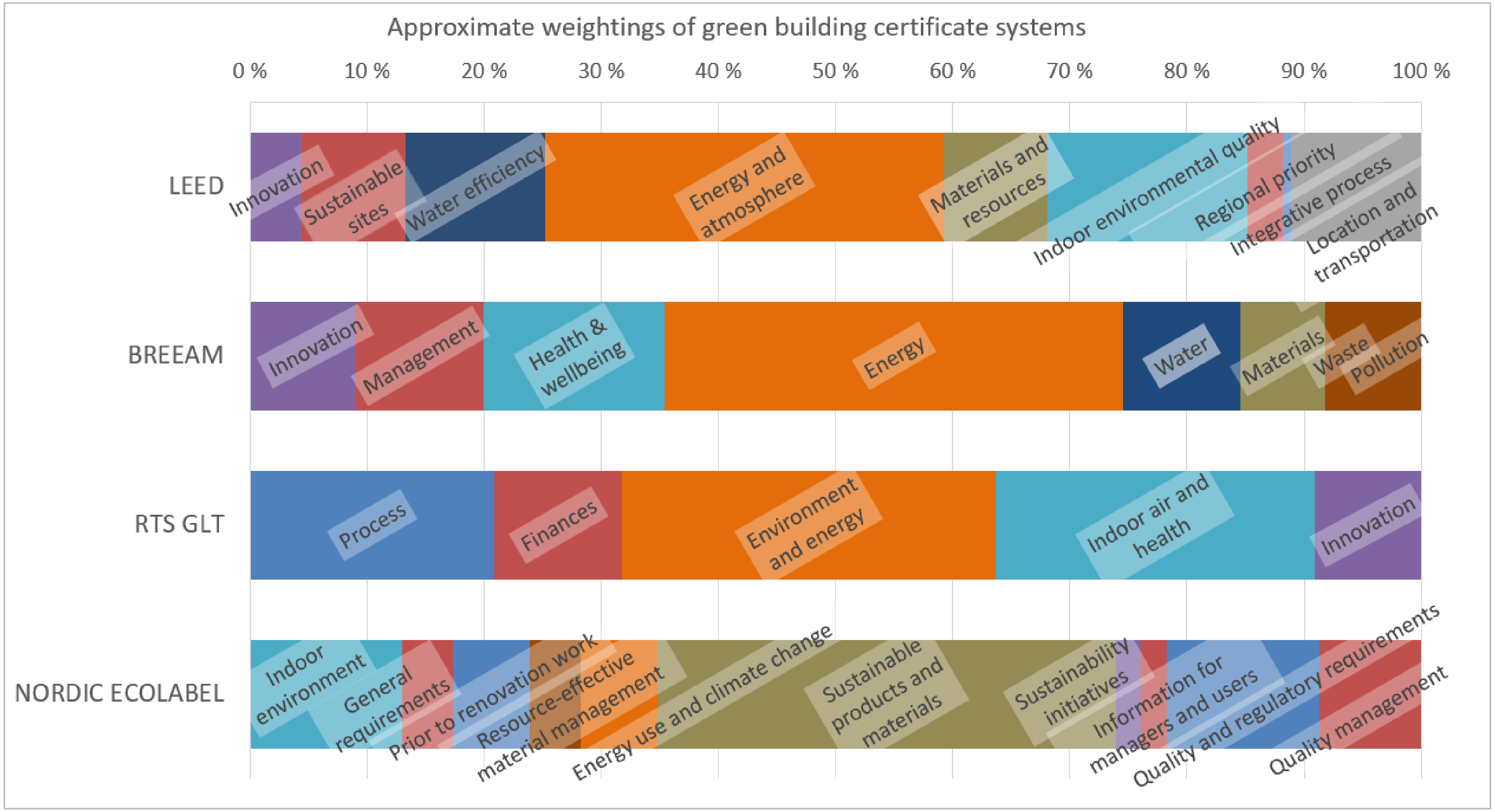

Figure 12. Approximate weightings of different certification systems' maximum points in given categories. Similar categories are colored similarly. Included criteria: LEED O+M: EB v.4 (USGBC 2018); BREEAM Domestic Refurbishment and Fit-out 2014 (BRE Global 2016); RTS residential buildings 2018 (RTS 2019a); Nordic Ecolabel repair construction 2017 (Ecolabelling Finland 2017).

Figure 12 shows that LEED and BREEAM have quite similar categories and weightings and focus much more strongly on energy than RTS GLT and Nordic Ecolabel. Nordic Ecolabel has divided its criteria to the highest number of categories, and the importance of sustainable materials in contrast to energy aspects is much higher. RTS GLT seems to lay great importance on indoor air aspects. Miljöbyggnad is not included because it has a different scoring system, while it divides the scoring quite evenly between categories Energy, Indoor environment and Materials (SGBC 2019b). The shares are not exactly the same for all certification schemes in the shown certification system, as there usually are slightly different weightings in each scheme depending on the building type and use. The differences are small: the weighting differences between e.g. LEED schemes for new and existing buildings (e.g. LEED B+D: NC and LEED O+M: EB) are only some percentage points (Rantanen et al. 2016, 6). Most of the certification systems have minimum requirements in different categories and depending on the certification system, they are expressed as obligatory criteria and/or a certain percentage of points that need to be received in order to reach a certain rating. When doing a proper comparison, also the required minimum points in some schemes and criteria should be included. A more detailed comparison of included criteria can be seen in Appendix 1.

There are several other national green building certification systems which are more adapted to the conditions in specific countries. For example, in Germany and Denmark, DGNB certification (Deutsche Gesellschaft für Nachhaltiges Bauen) is commonly used and France applies the HQE certification (Haute Qualité Environnementale). (FIGBC a.)

4.2 Finding suitable certification schemes

The following subchapters will search for certification scheme options for existing apartment buildings and for apartment buildings undergoing a building system renovation. The subchapters describe the process of finding the schemes in the most relevant certification systems.

4.2.1 LEED

LEED provides eight main certification schemes for different projects, and these are further divided to subcategories. The certifications are all currently adapted according to LEED version 4. The newest version LEED v4.1 is in beta stage and its contents will not be considered in this thesis, as the version is still under development and the instructions are only drafts. (USGBC 2019b; USGBC 2019c.)

At first glance, LEED seems to provide several certificates applicable for existing apartment buildings and just the right option might be challenging to find. According to information on LEED front page, for existing buildings that are being slightly improved or are not undergoing any renovations, LEED v4 O+M (Operations and Maintenance) can be used. For single-family homes as well as multi-family homes with one to six stories, LEED v4 Homes can be applied. (USGBC 2019b.) However, when using a tool for finding the suitable certification for each project, a more detailed list of certifications is shown. According to this tool provided by LEED, the suitable certification for an existing building depends on many aspects, and the recommended certification options can be seen in the following table. The possible options include certifications both from the BD+C (Building Design and Construction), O+M and ID+C (Interior Design and Construction) categories. (USGBC a.) For clarity reasons, only the options for residential buildings are shown.

Table 3. Choosing the appropriate LEED certification system for a residential building according to a test provided by LEED. *) this category includes any type of building excluding storages, hotels, schools and retail and is not, therefore, only for residential buildings. **) this category includes any type of building excluding hotels and retail and is not, therefore, only for residential buildings. ***) this category includes any type of building excluding storages, hotels, hospitals, schools and retail and is not, therefore, only for residential buildings. (USGBC a.)

	CERTIFICATION					
TYPE OF RESIDENTIAL BUILDING OR PROJECT	**BD+C: Homes**	**BD+C: Multifamily Midrise**	**BD+C: New Construction**	**BD+C: Core and Shell**	**O+M: Existing Buildings**	**ID+C: Commercial Interiors**
Single-family, new	**X**					
Multifamily, new, 1-3 stories	**X**					
Multifamily, new, 4-8 stories		**X**				
Multifamily, new, 9+ stories			**X**			
Residential, existing, operational efficiency improvement (*					**X**	
Residential, existing, interior fit-out (**						**X**
Residential, existing, major renovation - another team doing interior fit-out (***				**X**		
Residential, existing, major renovation – same team doing interior fit-out (***			**X**			

When looking at table 3, it can be said that it is not a simple task find the suitable LEED certification for an existing residential building. After some searching, LEED instructs to choose the BD+C Core and Shell only if over 40 % of the building's gross floor area is incomplete at the time of certification (USGBC 2014), which is not the case with existing buildings. According to a specialist, the ID+C: Commercial Interiors can be used when e.g.

the interiors in one floor are changed (Tähtinen 2019a), which makes the scheme unsuitable for building system renovations. Additionally, O+M: Existing Buildings can be used for buildings that have been fully operational for at least a year. Further, for larger residential buildings i.e. an existing multifamily building or complex with 20 or more units, O+M: Multifamily can be used. (USGBC 2014.) However, there are no O+M: Multifamily projects listed on LEED sites (Pekonen 2019) and because the same criteria are used for both EB and Multifamily, they can be more or less treated as the same scheme in this thesis. Some criteria are required to be fulfilled by different methods between EB and Multifamily, and it is likely, that in these cases the method intended for Multifamily is used when assessing an apartment building (Pekonen 2019).

The largest problem with finding the most suitable scheme is related to the unexplained renovation options "operational efficiency improvements" and "major renovations". LEED glossary defines major renovation in the BD+C: NC as "extensive alteration work in addition to work on the exterior shell of the building and/or primary structural components and/or the core and peripheral MEP (mechanical, electrical and plumbing) and service systems and/or site work", and typically during the renovation the space cannot be used for its intended purpose (USGBC 2019d). When "operational efficiency improvements" are executed in the building, the measures include e.g. restoring or applying interior fixtures or applying MEP and service system repair, replacement or upgrade and maintenance, according to LEED guidance (USGBC 2019e). According to specialists, the scope of BD+C: NC is not very strictly defined, but usually only the basic structure of the building remains unchanged and both interior building systems and external structures are renovated to some extent. A renovation focused solely on building systems could most probably use an O+M scheme. When being unsure about the suitability of a certification scheme, a LEED professional needs to confirm the project's or building's suitability with the help of USGBC, if needed. (Tähtinen 2019b; Kauppinen 2019a; Pekonen 2019.). As a conclusion, O+M: EB/Multifamily could be used for existing apartment buildings. The above-mentioned or BD+C: NC for buildings undergoing a building system renovation, depending on the number of apartments and extent of the renovation. However, BD+C: NC can most probably be used only if renovation measures are done also with the shell or envelope of the building and not only with the building systems.

4.2.2 BREEAM

BREEAM includes five certification schemes in total. BRE, like USGBC, offers a simple tool for finding a suitable certification scheme and technical standard, as it is dependent on the location country and building type. The international version is adapted to the country's regulations and standards, but even more adapted certifications are offered in a couple of countries, e.g. Sweden, USA and Austria, while the international version can be used for all the other countries. When choosing Finland, selecting a residential building and further choosing new construction, in-use and refurbishment and fit-out, the tool suggests BREEAM International New Construction, In Use and Refurbishment and Fit-out, respectively. (BRE 2019c; Rantanen et al. 2017, 12.)

When looking at the suggested technical standards (International Refurbishment and Fit-out, International In-Use), it is confirmed that the latter cannot be used for domestic buildings (BRE 2016, 23). The former, however, is marketed to include also domestic buildings (BRE 2019d), but the international version only seems to include non-domestic buildings (BRE 2015a, 13-14), and domestic buildings in the UK only are most probably included. This is confirmed by a BREEAM professional, and thus, the only option for existing or renovated apartment buildings in Finland is BREEAM Bespoke (Ekelund 2019). BREEAM Bespoke is meant to be used for projects outside of the scope of any existing BREEAM Technical standards. Criteria from related BREEAM scheme are chosen and modified to suit the project, its function and location. (BRE 2015b.) If the renovated building was located in the UK, BREEAM UK Domestic Refurbishment and Fit-out could be used, but BREEAM In-Use is not suitable for domestic buildings in UK either (BRE 2019d; BRE 2019e). The suitable BREEAM scheme should nevertheless be confirmed by a BREEAM professional and by BRE in unclear cases. When starting the Bespoke process, BRE Global needs to be contacted in any case for asking a proposal for tailoring. (Tähtinen 2019b.)

4.2.3 RTS Green Leadership Tool

As RTS GLT is a relatively new classification system, not enough information about finding the appropriate type of certification can be found online. More information is provided via email. RTS GLT has separate criteria for residential buildings and for offices and service buildings. The criteria are based both for new construction and renovation of existing buildings, and they can also be used for when the original use of the space changes. The criteria are applicable for any types of buildings. However, the criteria cannot be used for existing buildings. RTS is currently developing criteria that can be used for maintaining an existing building and taking the tenants' needs as well as environmental impacts into account. The criteria for existing offices and service buildings is completed during summer 2019 while creating the criteria for existing residential buildings still needs to be started (Sariola 2019a; Sariola 2019b; Sariola 2019c.) In conclusion, the criteria for residential buildings can be used for a residential building under construction or renovation, but the upcoming classification for existing buildings can unfortunately not be used in this thesis.

4.2.4 Nordic Ecolabel

Nordic Ecolabel or Nordic Swan has a set of criteria for new construction and repair construction separately. The criteria are applicable for any residential buildings, schools, offices, nursing homes and summer houses, and they are valid until the last day of 2021. (Ecolabelling Finland; Ecolabelling Finland 2017, 4-5.) The certification criteria are not applicable for existing buildings. (Holopainen 2019b.) Furthermore, the criteria for renovation can be only used in projects where the scope of the renovation (excluding demolition) covers at least 25 % of the value of the building (excluding land value) and/or the renovation covers at least 25 % of the surface of the building envelope. The repaired part should be a well-defined part of the building. (Ecolabelling Finland 2017, 5-6.) In addition, the larger extent the renovation has, the easier it is to apply the criteria (Kauppinen 2019a).

4.2.5 Miljöbyggnad

Miljöbyggnad offers certification standards for virtually all types of building projects. The certification can be granted many different kinds of building types, including apartment buildings. The criteria for new construction are applicable for buildings that have been in use for a shorter time than five years, which covers a significant share of the building stock. If the building has been in use for more than five years, the criteria for existing buildings can be used. Miljöbyggnad has also criteria for buildings under renovation, and the assessment of the criteria is done by using both the manual for new construction and for existing buildings. With some of the criteria, assessments of the building need to be done both before and after the renovation. The current version of Miljöbyggnad is Miljöbyggnad 3.0. (SGBC 2015a, 9-24.)

4.2.6 Conclusion on suitable certification schemes

According to the previous subchapters, LEED O+M: EB/Multifamily seems to be suitable for certifying existing apartment buildings in Finland. As the assessment in these certifications is focused on the operation and maintenance of the building, these certifications for existing buildings need to be renewed after five of years (USGBC 2013, 13). When it comes to apartment buildings undergoing a building system renovation, LEED O+M: EB/Multifamily as well as RTS GLT and Nordic Ecolabel seemed to be appropriate. In addition, Miljöbyggnad can be used to certify both of these project types in Sweden, and BREEAM Bespoke can possibly be adapted for apartment buildings under renovation. If also the exterior of the building is renovated to some extent in addition to renovating the building systems, LEED BD+C: NC could also be used. However, as the exterior shell is not usually a part of a building system renovation by definition, LEED BD+C: NC is excluded from the suitable certification schemes.

Furthermore, the suitability of each certification system should be confirmed by a professional, as the suitability is usually unclear according to the previous subchapter. This is the case especially with renovations, since their scope varies significantly. Certificate suitability in terms of criteria for the examined building scope is assessed in the empirical part.

4.3 Certification process and fees

The certification process starts with an initial analysis of the possible certification schemes simultaneously with the project planning. After choosing the most suitable certification scheme, the certification process is quite similar irrespective of the chosen scheme. The desired certification level to which the project will be aimed at is chosen and the project is registered for application. The project group is informed about the certification and the project is planned in accordance with the certification criteria and the needed additional analyses are done as well. When it comes to the actual construction phase, the project managers are informed about the supplementary requirements the certification sets on the project and the building is steered to be able to achieve the set targets. The needed documents and other verifying material are collected during the construction phase. The final certification application is composed and the project is certified based on a third-party assessment. Additional steering meetings or intermediate certification assessments are done during the process, if needed. (FIGBC 2018a, 5.) The process is also shown in the following figure.

Figure 13. Simplified certification process. (FIGBC 2018a, 5.)

Figure 13 is only a simplified description, and the certification process is different with different certification schemes, so it is important to familiarize oneself with the requirements in question. In addition to these process steps, most certification systems require regular reports on relevant data and some even regular renewal of the certification.

The certification level is determined differently in each certification. Certification points need to be calculated in all LEED, BREEAM and RTS GLT certifications and the final certification level is based on the total points as shown in table 2, and the required criteria need to be filled in any case. All the criteria in Nordic Ecolabel certification for renovated buildings are obligatory and no points are therefore calculated. In the case of Miljöbyggnad, the certification level is not determined by points but by a table shown in the figure below.

		Indicators in 3.0	Indicator	Aspect	Area	Building
Energy	1	Heat demand	BRONS	BRONS	BRONS	BRONS
	2	Solar gain	SILVER			
	3	Energy consumption	BRONS	BRONS		
	4	Share of renewable energy	SILVER	SILVER		
Indoor environment	5	Noise	GULD	GULD	SILVER	
	6	Radon	GULD	SILVER		
	7	Ventilation	SILVER			
	8	Moisture safety	BRONS	BRONS		
	9	Thermal climate, winter	SILVER	SILVER		
	10	Thermal climate, summer	SILVER			
	11	Daylight	GULD	GULD		
	12	Legionella	SILVER	SILVER		
Material	13	Logbook of building materials	GULD	GULD	GULD	
	14	Phasing out hazardous substances	GULD	GULD		
	16	Removing hazardous substances	SILVER	SILVER		

Figure 14. Certification tool in Miljöbyggnad for buildings under renovation, translated from Swedish. The rating classes Brons, Silver and Guld indicate certification levels Bronze, Silver and Gold. Modified after (SGBC 2019b.)

In the certification tool for Miljöbyggnad shown in figure 14, each cell representing a criterion or indicator is given the rating Bronze, Silver or Gold. The indicator rating is decided by floor ratings, which is determined by room ratings. After this, the indicator ratings automatically determine the aspect rating, which, in turn, determines the area rating. The three area ratings determine the rating for the whole building. There are specific rules for the determination of the ratings, but the lowest rating is always the determining rating for the next step, but this rating can usually be upgraded to the next-highest rating if at least half of the other ratings are higher in the current step. However, the lowest area rating determines always the rating for the whole building. For example, only one Bronze indicator rules out the possibility to receive a Gold building rating, and one Bronze area rating gives a Bronze building rating, even if the other two area ratings were Gold. (SGBC 2015, 14-16.)

Only BREEAM requires a certified consultant in the process. The other certification schemes, LEED, RTS GLT, Nordic Ecolabel and Miljöbyggnad, do not require a consultant. However, both LEED and BREEAM give additional points if official LEED or BREEAM "accredited professionals" are used in the process. When it comes to languages, LEED and BREAAM criteria are presented in English and parts of the certification evidence have to be translated to English, while with BREEAM, the evidence can be submitted in Finnish provided that BREEAM's translation service is used. The criteria of RTS GLT are in Finnish and the evidence for certification can also be presented in Finnish both in the case of RTS GLT and Nordic Ecolabel (FIGBC 2018a, 4). The criteria of Nordic Ecolabel can be found in Finnish, Swedish and English, but some of the additional documents are still only available in the latter two languages. The criteria of Miljöbyggnad are only provided in Swedish.

The following table shows the fees related to certifying a building with the analyzed certification methods. LEED O+M: EB and LEED O+M: Multifamily are both shown in the column LEED O+M. The charges related to LEED certification are those for non-USGBC members. Members get approximately 15-20 % lower charges (USGBC 2019f). The shown Miljöbyggnad prices are also for non-SGBC members: 43 % higher than those for members (SGBC 2019c). In the case of BREEAM, the initial prices are those of BREEAM International Refurbishment and Fit-out as it is assumed that these criteria could be used for a building under renovation when adapting the criteria in Bespoke process. The certification fees of BREEAM depend on the number of project parts assessed, as only the relevant parts are included. The project parts in RFO scheme are Fabric and Structure, Core Services, Local Services and Interior Design. (BRE Global 2017.) In the case of building system renovation, assessing the Core and Local Services only might be sufficient. The certification fees of all systems mostly depend on the gross area of the project, and the prices for the most likely gross areas are shown.

Table 4. Approximate charges of the different certifications for buildings under repair, as of March 2019. In the case of Miljöbyggnad, also for existing buildings in parentheses. VAT is already added to the prices in the last four columns based on the current VAT in the certificate countries. ([1] USGBC 2019f; [2] BRE Global 2016; [3] RTS 2019b; [4] SGBC 2019c; [5] Ecolabelling Finland; [6] Tähtinen 2019b.)

	LEED O+M and BD+C [1]	**BREEAM RFO Bespoke** [*, 2] (VAT 20 % added)	**RTS GLT** [3] (VAT 24 % added)	**Miljöbyggnad** [4, *] (VAT 25 % added)	**Nordic Ecolabel** [5] (VAT 24 % added)
Application	1320 €	1224 €	2294 €	1410 € (995 €)	3720 €
Certification	O+M: 0.4357 €/m², min. 1980 € BD+C: 0.6441 €/m², min. 3009.60 € [**]	1000-5000 m²: 1-2 parts: 1583 € 3 parts: 1921 € 5000-50000 m²: 1-2 parts: 2135 € 3 parts: 2612 €	Less than 5001 m²: 3658 € 5001-20000 m²: 4774 €	Less than 5000 m²: 9951 € (4727 €) 5000-10000 m²: 10946 € (5224 €)	0.15 % of the contract price [***], min. 2480 €
Othercosts	Criteria related to energy & HVAC: 704 €/criterion Other criteria: 440 €/criterion	Tailoring the criteria: several thousands (€) [6]	Calculation tool license: 186 €/year		Extra visits to the building site: 620 €

*) Currency rates (SEK/EUR, GBP/EUR) as of 14 May 2019.
**) Apply when project size is less than 23225.76 m², which is usually the case with single apartment buildings. Converted from unit €/sq ft.
***) The prices of research are not included. If the contract price exceeds 10 000 M€: charge is 0.05% of this exceeding price.

According to table 4, the certification systems have quite varying fee compositions, but the total costs of small projects seem to range between 6000 euros to over 11 000 euros, and even more in larger projects. LEED stands out as the most expensive system because of expensive criteria assessment while the high certification charge in Nordic Ecolabel is distinct, but the actual cost of BREEAM Bespoke is quite unsure. With practically all certification systems, additional costs occur if e.g. additional reviews or shorter process times are requested for or a certified assessor or consultant is hired. The charges of Miljöbyggnad are much higher compared to the other Nordic certification systems, but being a member of SGBC lowers the charges by almost a third. Because the certifications for existing buildings are valid for only a couple of years, recertification fees occur regularly for these types of projects.

5 RESEARCH METHODS

The empirical part is divided to a general part, where the possible impacts of optimal building system renovations on green building certifications are estimated and to a practical part, where the possible impacts are examined by estimating points for a case building. The scope of the first result chapter is Finnish apartment buildings built during 1976-2002 as described in chapter 2, and the chapter also aims at finding the relevant criteria for answering the research question by analyzing criteria documents from the certification bodies and analyzing the suitability of these certifications. The scope of the second result chapter is the case building in Kerava, Southern Finland, and this chapter also describes the building and its planned renovation, laying the foundations for certification point assessment. Information for the study is gathered mostly from the previous chapters in the thesis, a webpages and other electronic sources, books and previous studies. Also, opinions and insights are asked from experts and people working with the case building. The structure of the study can also be seen in the following figure.

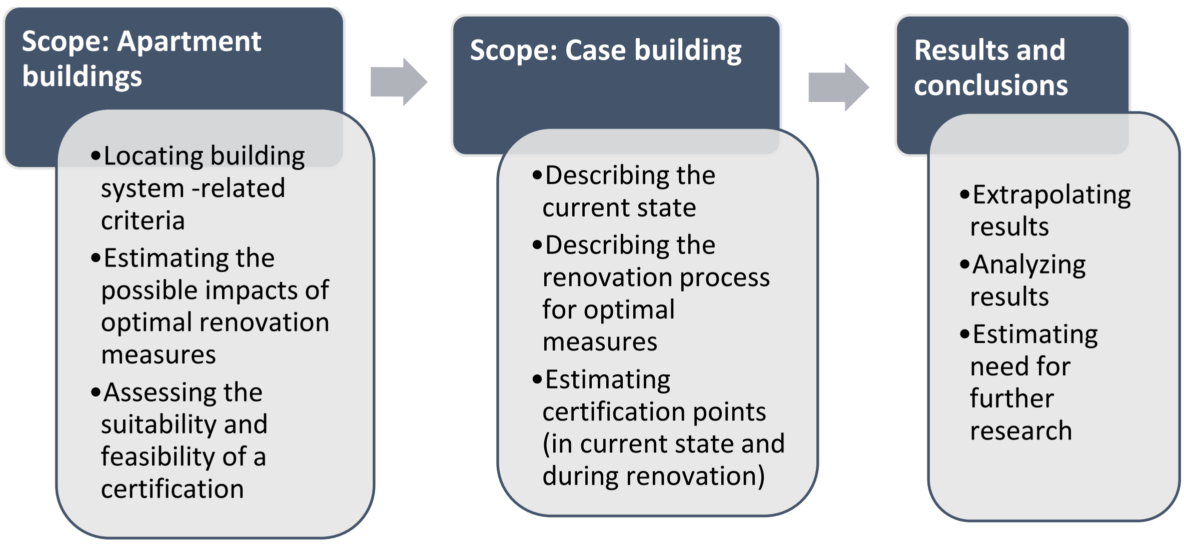

Figure 15. Structure and contents of the empirical part. Results of chapter 6 are analyzed throughout the chapter, while results of chapter 7 are analyzed in chapter 7.4, and the analyzing is put together in the conclusions.

Both empirical chapters build mostly on certification criteria and point assessments and analyses. These assessments are very much estimations and are mostly based on educated guesses and some calculations, thus, mostly qualitative research methods are used.

However, all suitable reference material mentioned above is utilized to provide the best possible results during the limited timeframe of this thesis and possible inaccuracies are always mentioned to ensure transparency. Because of the limited information available especially about the usage of the Nordic certification systems and especially in apartment buildings, estimations cannot be avoided, despite their uncertainty. In order to simplify the calculations in the empirical part, average values for possible energy savings are used. Received points and the weightings are always rounded according to general rules unless the criterion specifically requires rounding down.

Case studies as research methods are criticized, thus, in order to conduct a proper case study, it is important to design and conduct the case study well. It would be important to present the study in a comprehensive and detailed way with good data. (Yin 1994, 1-16.) Typically, a case study is suitable for answering research questions beginning with “how” or “why”. A case study can be using any kind of mix of qualitative and quantitative research methods. These studies can be based on one or several cases. (Yin 1994, 1-16.) In this thesis, a single-case study is used, inside which mostly qualitative assessments are made, but as much quantitative research is used as is found appropriate and possible. As much data on the case building is retrieved from original construction and HVAC plans and from experts. The actual results of the pilot project in the case building, in other words, the building system renovation, cannot be used as data in this thesis as the results will be received later. Therefore, a complete analysis including e.g. energy modeling and LCC calculations cannot be presented as there is no actual data to be compared.

A case study is generally designed by first setting the research questions, propositions and unit(s) of analysis, and then deciding how to link data to the propositions and how to interpret the findings (Yin 1994, 19-27). In the case of a single-case study, the unit of analysis (in this case, apartment building) has to be chosen carefully so that it is relevant for answering the research questions (Yin 1994, 44). The research question in this thesis is how a building system renovation could affect green building certification points in an apartment building, but the suitability of such certifications for these buildings is studied as well. The case building is well representative of the building stock that is analyzed throughout this study, which makes it a suitable unit of analysis. The result interpretation is done initially in chapter 7.3 and analyzed together with the results from chapter 6 in conclusions (chapter 8).

6 IMPACT OF BUILDING SYSTEM RENOVATIONS ON GREEN BUILDING CERTIFICATION

This chapter focuses on finding the possible impacts of a building system renovation on scoring in green building certification systems for apartment buildings. The estimations present the maximum impact of a building system renovation. The scope consists of apartment buildings built during 1972-2002. The suitability and feasibility of certification schemes for this building type is analyzed as well.

6.1 Relevant criteria related to renovation of building systems

All of the certifications have slightly different weightings and focus areas. Therefore, assessments on focus areas and especially on those related to technical systems and energy use need to be done. The share of criteria or points affected by a building system renovation determines the possible impact of a building system renovation in an apartment building pursuing a green building rating. Choosing the criteria that can possibly be affected by a building system renovation depends on defining the scope of the renovation. The renovation can include at least the following measures:

a) the measures done to improve the performance of the building systems, and/or
b) the efficiency of the renovation process itself (handling safety, management, waste), and/or
c) other measures easily done during renovation, such as creating logbooks, reports and small installations.

Furthermore, defining which measures are easily done while renovating (group c) is very subjective and depends on the type of renovation itself, the willingness of the project parties to put additional effort and the available resources for these additional resources. Therefore, choosing the relevant criteria is not a straightforward task and no absolutely correct set of criteria can be presented.

As can be seen in figure 12 already, the importance of energy aspects is low in RTS GLT and even lower in Nordic Ecolabel. Therefore, it could already be estimated that the impact of a building system renovation is larger in LEED and Miljöbyggnad. Also, a study analyzing the impact of energy companies and district heating on a green building certification concluded that BREEAM and especially LEED focused more on energy, particularly in the new construction criteria, when compared to RTS GLT and Nordic Ecolabel. (Rantanen et al. 2017, 38-41). However, now the criteria for renovation are assessed instead.

Calculating the share of relevant criteria is not a straightforward task, because LEED has some obligatory criteria and Nordic Ecolabel has only obligatory criteria without any points or weightings. In addition, Miljöbyggnad calculates the final rating based on weightings in several steps. In Nordic Ecolabel one obligatory criterion is decided to represent one point. In the case of LEED, the obligatory criteria are considered separately. Because determining the value of an obligatory criterion is difficult and misleading in any case, the following results are not completely accurate. All the obligatory criteria need to be filled nevertheless and they are, therefore, more important than the voluntary criteria. The minimum points required in specific criteria for certain certification levels are not included in the analyses.

The complete criteria of the chosen certification schemes can be found in Appendices 2-5. The following two tables present the criteria that can be affected by building system renovations. The first table presents the relevant criteria from American LEED O+M and Nordic Ecolabel. The next table includes the criteria from Finnish RTS GLT and Swedish Miljöbyggnad. BREEAM Bespoke is excluded from the analysis in this subchapter as it is unclear what criteria would be included and the chosen set of criteria depends a lot on the extent of the renovation. Only the criteria affected by measures belonging in the a-group in the alphabetical list shown above are shown in the following tables because the aim was to choose the criteria which can quite clearly be affected by a building system renovation. The criteria affected by groups a-c were chosen based on going through requirements of each criterion in each certification system. The appendices 2-5 contain comments explaining the decisions of classifying the criteria in groups a, b, or c, in cases where there were major uncertainties when determining the possible impact of a building system renovation.

Table 5. Criteria affected by a building system renovation in LEED O+M and Nordic Ecolabel certification schemes (USGBC 2018; Ecolabelling Finland 2017). NB! The differences between O+M: Multifamily and O+M: Existing Buildings is small – EB gives one more point from criterion Interior lighting (total 2 points), and the executions of filling the criteria differ occasionally between Multifamily and EB.

LEED O+M: EB/MULTIFAMILY		**NORDIC ECOLABEL**	
Criterion	**Weighting of credit (as in Multifamily)**	**Criterion**	**Weighting of credit**
WE Indoor water use reduction	4.6 % (also required)	O8 Indoor air quality	2.2 %
WE Building-level water metering	required	O9 Radon	2.2 %
WE Cooling tower water use	2.8 %	O11 Ventilation	2.2 %
WE Water metering	1.8 %	O14 The energy demand of the building after renovation	2.2 %
EA Minimum energy performance	required	O15 Lighting	2.2 %
EA Building-level energy metering	required	O16 Energy-efficient white goods	2.2 %
EA Fundamental refrigerant management	required	O35 Sustainability initiatives	2.2 %
EA Optimize energy performance	18.4 %		
EA Advanced energy metering	1.8 %		
EA Demand response	2.8 %		
EA Renewable energy and carbon offsets	4.6 %		

EA Enhanced refrigerant management	0.9 %		
EQ Minimum indoor air quality performance	required		
EQ Enhanced indoor air quality strategies	1.8 %		
EQ Thermal comfort	0.9 %		
EQ Interior lighting	0.9 %		
total	**41 %**		**16 %**

Table 6. Criteria affected by a building system renovation in RTS GLT and Miljöbyggnad certification systems (RTS 2019a; SGBC 2015b; SGBC 2019b). NB! The rating system of Miljöbyggnad is not based on weighting and changing the rating system is always a rough approximation and the final rating is decided by rules described in chapter 4.3.

RTS GLT		**MILJÖBYGGNAD**	
Criterion	**Weighting of credit**	**Criterion**	**Weighting of credit**
Y1.1 Life cycle carbon footprint	6.4 %	Heat demand	5.5 %
Y2.1 Energy efficiency	7.3 %	Energy consumption	11 %
Y2.2 Measuring energy use	2.7 %	Share of renewable energy	11 %
Y2.4 Efficiency of systems	1.8 %	Noise	5.5 %
Y3.1 Efficiency of water use	2.7 %	Ventilation	2.75 %
S1.1 Thermal conditions	5.5 %	Thermal climate, winter	2.75 %
S1.2 Indoor air quality	6.4 %	Thermal climate, summer	2.75 %
S1.3 Opportunities for occupants to make adjustments	1.8 %	Legionella	5.5 %
S2.2 Quality of lighting	1.8 %	Removing hazardous substances	11 %
total	**36 %**		**61 %**

Additionally, a building system renovation could help filling 50 % of LEED's obligatory criteria (six out of 12), which are required to be filled in order to receive any rating. In RTS GLT the Innovation criterion is considered to give additional points. However, innovation-related criteria are assumed to be included in total points in this thesis, but they are not considered to be affected by measures in the a-group, thus, to be affected by building system renovation measures.

There can be several different outcomes when deciding which criteria are related to energy renovations as mentioned before. A building system renovation does not automatically affect the shown criteria in tables 5 and 6, but it can affect these criteria, depending on the included renovation measures. Because of the extent of various building system solutions, the actual shares of maximum impacts of building system renovations can be larger than those in tables 5 and 6. However, some criteria shown in these tables are partly affected by other units in the building, making the actual impact of building system renovations smaller.

Miljöbyggnad offers two manuals for assessing the criteria: one for new construction and one for existing buildings. In the case of renovation, it is instructed to use the assessment method which better suits the renovation; in other words, when renewing the whole ventilation system, for example, the assessment method for criteria Ventilation in the manual for new construction should be used, but when reconstructing only parts of the ventilation system, the manual for existing buildings should be used. (SGBC 2015, 23.) Because the manual used and consequently, the assessment method, is determined by the extent of the renovation, the actual impact of renovation measures can differ from the impact presented in this thesis. The manual for existing buildings is mainly used in this thesis, but in cases of extensive renovation measures, the manual for new construction is used.

The criteria most probably affected by measures belonging to groups b and c are shown in appendices 2-5 with grey highlighting. These are not considered as much in this thesis as the a-group, but these are very important when gathering green building certification points during any kind of renovations. Many of the criteria related to measures belonging in groups b-c are normally included or can easily be included in a typical renovation process. Basically, only the criteria not affected by any kind of building system renovation measure or a minor additional task are left unmarked in the Appendices 2-5 – this means that only the structure-related measures are not marked. When looking at the criteria on which doing certain additional measures, reports and the like can affect when doing a building system renovation, the results become even more unsure when comparing to tables 5 and 6, as the simplicity of doing a certain measure is subjective and depends on the project. Many of these measures are management-related. However, the weighting of such measures in LEED O+M: EB is approximately 35 %, in Nordic Ecolabel 71 %, in RTS GLT 45 % and in Miljöbyggnad 22 %, as also shown in the following figure. Additionally, these extra measures can help with filling the rest of 50 % of the 12 obligatory criteria in LEED O+M.

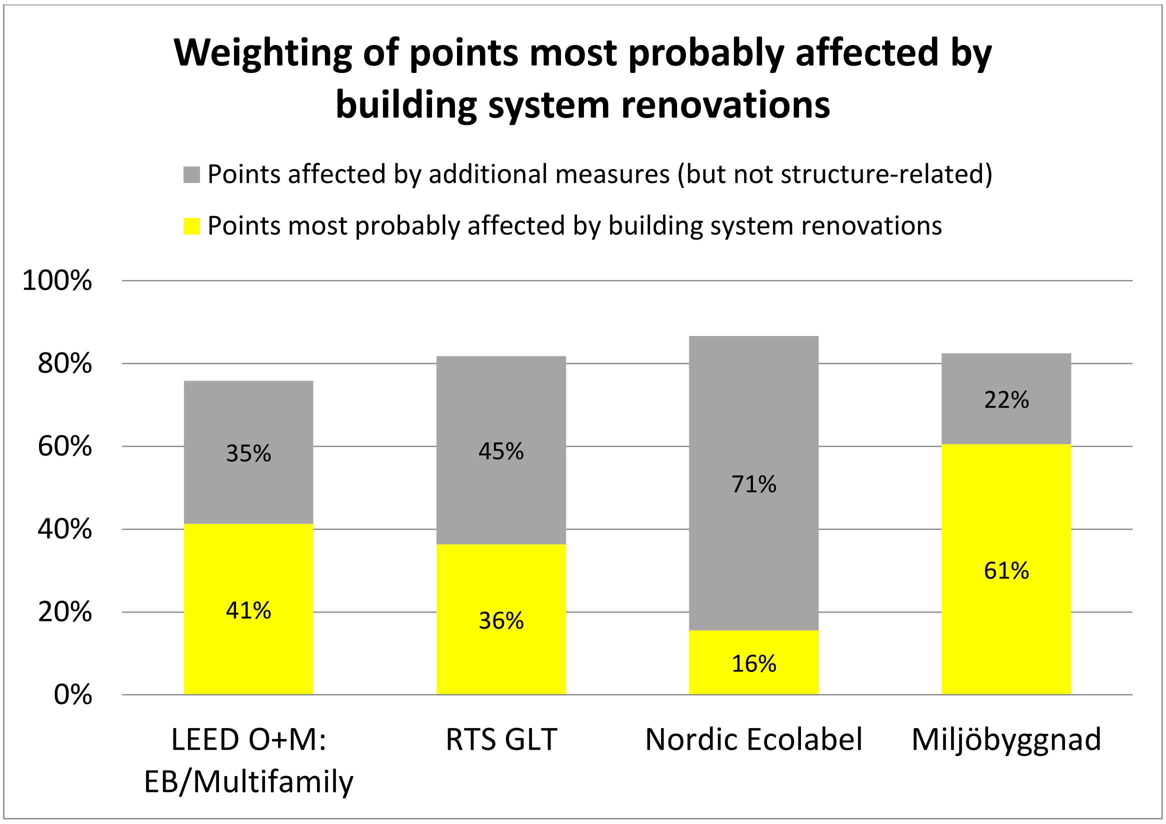

Figure 16. The weighting of building system renovation related points in four green building certification systems as well as the weighting of points affected by additional measures. In the case of LEED, obligatory criteria are not taken into account.

Because the criteria of Nordic Ecolabel mostly consists of creating different logbooks, assessments and reports especially on used materials, most of the criteria could be filled by doing some additional work, which explains the high weighting of such criteria in figure 16. Also LEED O+M and RTS GLT include many operation-related criteria, which can more or less easily be done while operating or renovating the building. In the case of LEED, this is partly because these criteria are also meant to be used for existing buildings undergoing only minor improvements. Miljöbyggnad has few criteria, which can also cause the high percentage of criteria on which a building system renovation could affect. Miljöbyggnad has a very different scoring system and the above-mentioned weightings are more inaccurate than in the other certification systems. All in all, the certification systems are focused on the process of renovation so these high numbers are not unexpected and another assessor would probably arrive at a slightly different conclusion.

6.2 Impact of different renovation options on certification points received

The energy renovation options shown in the following table are chosen based on chapters 3.2 and 3.3 and their suitability for the case building. As mentioned before, measures improving only the envelope of the building are excluded.

It is assumed that a typical Finnish building built during 1976-2002 as described in chapter 2 is examined here. There are generally very many measures considered, but most of them do not prove to be cost-effective for such an apartment building. The table below presents the measures that are most probably suitable according to studies mentioned in this thesis in chapter 3.2, as well as an estimation of their actual relevance. There are several minor renovation measures that can be effective, but they can be considered more as maintenance measures and were mostly excluded. These include simply renewing the existing installations or readjusting the heating system, for example. Furthermore, only energy-saving or renewable energy based renovation options were chosen.

Table 7. Considered renovation measures based on studies mentioned earlier and their estimated relevance (Nummelin 2019a; Kauppinen 2019b). The measures considered most relevant are written in bold.

RENOVATION MEASURE	RELEVANCE
Installing an EAHP	Relevant
Installing an air-to-water heat pump	Not as relevant, as it cannot provide heat year around
Installing a GSHP	Relevant
Installing a biofuel boiler	Not as relevant in a building with district heating
Upgrading the ventilation system and adding heat recovery	
centralized mechanical supply and DCV	Not was relevant – expensive to add mechanical supply, can be cost-effective to add apartment-specific supply when renovating the façade (Pylsy 2011, 99)
apartment-specific supply system and DCV	
Adding building automation	
apartment-specific water metering and billing (water consumption savings in average 10-30 %, heating energy savings 3-9 % (Motiva 2018a))	Quite relevant – not as cost-efficient when installing afterwards and when having several risers
switching to motion-controlled LED lighting in common spaces	Relevant
Switching to low-temperature radiators	Not as relevant – feasible when having to renew radiators anyway
Installing wastewater heat recovery (efficiencies from Hirvonen et al. 2018, 6-7)	
Active (equipped with heat pump, 70 %)	
Passive (only a heat exchanger, 30 %)	Not as relevant – heat production is far from constant, problems with legionella can occur
Installing solar thermal collectors	Quite relevant
Installing solar PV panels	Relevant

Installing GSHP can be more feasible if excavations need to be done in the building area otherwise as well. The Finnish building code makes the utilization of wastewater heat recovery difficult, as it can be interpreted that DHW cannot be preheated at all because the minimum water temperature in the system is 55 °C (D 1047/2017, 6 §). However, using a heat pump to increase the temperature makes the use more acceptable, when the water is heated to goal temperature instead of simply recovering heat. Based on table 7, the most relevant measures are chosen for further considerations as shown in the following table. The relevance varies largely between renovation projects and renovated apartment buildings. The aim was, however, to choose the most relevant measures based on mostly studies and guidance (Nummelin 2019a) and also to choose measures that are easily defined, rather than a package of several measures. Typical assumptions as presented in earlier chapters are also shown in the next table, but the actual energy reduction values depend on the project and installation.

Table 8. Examined renovation measures and simple assumptions related to them necessary for assessments. Assumptions gathered from previous chapters. NB! Electricity and total energy reductions are based on electricity used in common spaces only.

	RENOVATION MEASURE	**ASSUMPTIONS**
1.	Installing EAHP, COP 4	Total energy savings 40 %, decreases district heating use by 70 %
2.	Installing GSHP, COP 4.5	Total energy savings 60 %, decreases district heating use by 90 %
	Adding building automation	
3.	apartment-specific water metering and billing	Water savings 20 %, heating energy savings 6 %
4.	switching to motion-controlled LED lighting in common spaces	Total electricity consumption savings 12 %
5.	Installing active wastewater heat recovery (eff. 70 %)	Total heating energy savings 11 %, when installed near showers, increases electricity consumption
6.	Installing solar thermal collectors	Decreases district heating use by 12.5 %
7.	Installing solar PV panels (40 kW_p)	Decreases bought electricity use for common spaces by 28 000 - 40 000 kWh (by approx. 50-70 %)

Only the criteria most probably affected by measures in the a-group, in other words, most possibly directly affected by a building system renovation, are included. These criteria are shown in tables 5 and 6. The criteria most probably affected by measures belonging to groups b and c are not considered because average renovation-related practices are difficult to define. However, these are important to take into account when estimating the total impact a certain renovation project has on certification system points.

The aim of the following table is to show the absolute impact of the renovation measure without taking the current state of the building too much into account. However, it turned out that some initial consumption values had to be calculated or estimated for buildings. The points are estimated assuming that the existing systems in the building are similar to those in a typical apartment building built during 1976-2002. The assumptions in table 8 and typical building-specific values based on earlier chapters are used in simple calculations and estimations when needed. The estimations for each criterion are presented in appendices 6-9 with comments and simplified calculations are shown in appendix 10. The table below presents only the total point impacts, which are obtained by multiplying the weighting of a criterion with the estimated impact of a renovation measure on the criterion or by calculating the share of added points from the total points.

Table 9. Estimated point impacts when doing renovation measures shown in table 8, as percentages of the total available points. The stars in LEED column indicate how well the measure helps fulfilling obligatory criteria. NB! Miljöbyggnad has a different scoring system according to chapter 4.3, and the weightings are always approximations. Furthermore, each criterion in Nordic Ecolabel is assumed to have a 2.2 % weighting as described in previous subchapter.

Renovation measure	**LEED O+M: EB/ MULTI-FAMILY**	**RTS GLT**	**Nordic Ecolabel**	**Miljöbyggnad**	**average impact**
1 (EAHP)	**16.3 %** **	**5.3 %**	**2.9 %**	**18.1 %**	10.7 %
2 (GSHP)	**22.7 %** **	**7.0 %**	**3.3 %**	**21.2 %**	13.6 %
3 (water metering)	**4.5 %** ***	**1.4 %**	**0.4 %**	**1.1 %**	1.9 %
4 (controlled LED)	**0.9 %**	**2.1 %**	**2.8 %**	**0.3 %**	1.5 %
5 (wastewater heat recovery)	**1.8 %**	**0.9 %**	**2.5 %**	**4.0 %**	2.3 %
6 (solar thermal)	**1.8 %** *	**0.9 %**	**2.5 %**	**4.6 %**	2.5 %
7 (solar PV)	**1.8 %** *	**0.0 %**	**2.5 %**	**4.0 %**	2.1 %
max. reachable share	41 %	36 %	16 %	61 %	

In the case of LEED, fulfilling obligatory criteria was not included in the percentages, but the more “*” symbols a measure has in table 9, the greater impact on obligatory criteria it has. All measures had at least a small impact on criterion EA Minimum energy performance, but measure 3 had clearly the largest impact on all obligatory criteria, followed by slightly less impactful measures 1 and 2. Measures 6 and 7 were estimated to have a medium impact on obligatory criteria.

Electricity consumption increased significantly with measures 1 and 2, especially when household electricity was not taken into account. This caused high E-values as shown in appendix 10, as the coefficient for electricity use in equation 2 is 1.2, while for district heating it is 0.5. This reduced the positive impact of heat pumps in RTS GLT and Nordic Ecolabel certification systems. In the Swedish building code and therefore, Miljöbyggnad criteria, the coefficient for district heat is 1.0, making the impact of installing a heat pump larger. The small amount of electricity that is usually used in common spaces can be seen as low impact of installing PV panels.

Based on the results, the impacts of installing an EAHP or GHSP are the clearly largest of feasible building system renovation options regardless of the certification system. Measures 3 and 5-7 have a similar, rather small impact in average, while motion-controlled LED lighting impacted the least. Because only building system -related criteria often focused on performance was assessed, the largest impacts came from measures with high energy savings. As was stated in chapters 4.1 and 6.1, LEED is very focused on energy aspects, resulting to high scores in table 9. The weighting of Miljöbyggnad is different as explained in chapter 4.3, resulting to inaccuracies in table 9. RTS GLT requires clearly either very high-performance building systems or also improvements on the building envelope, and it does not give as many points on renewable energy solutions as the other systems. LEED O+M focuses on water efficiency more than the other systems, which is probably because water scarcity is not as severe a problem in the Nordic countries as it is elsewhere. This gives water-saving measures high scores in LEED assessment.

These individual energy-saving actions have relatively small impacts on received points as seen in table 9. While options with very high energy-saving potential have a significant impact on the points, measures improving indoor air quality would result to clearly higher points. This is because all the assessed certification systems value indoor air quality, operative temperature and PPD (predicted percentage of dissatisfied) highly in the rating and none of the selected measures increase the incoming air flow, filter it better nor heat it, reducing the achievable points. Measures proven to reduce the emissions the most, i.e. adding at least well-designed mechanical supply ventilation system, would result to considerably higher scores.

In the case of LEED especially, it was often unclear whether household electricity was to be included in the calculations. Because household electricity forms approximately 70 % of total electricity use in an average building according to Appendix 10, including or excluding household electricity impacted greatly on reduction or increase percentages as used frequently for rating decisions. In LEED calculations it was chosen to be excluded. If it was included, the energy reduction in criterion EA Optimize energy performance would be 16 % lower, reducing the LEED scores by a few points (in this case, only for measure 1). The instructions of RTS GLT, Miljöbyggnad and Nordic Ecolabel were more easily available and usually easier to understand. Impacts were occasionally difficult to estimate, because they often depend on the initial values in the building. These values were only estimated, which means that the values are different in cases of real buildings. The estimations contain inaccuracies, in some cases it was challenging to estimate the impact, e.g. when the criteria were obligatory (Miljöbyggnad, Nordic Ecolabel), when the evaluation was based on initial values and when it was uncertain whether household electricity was to be included (LEED O+M). It has to be noted that in this case only approximately a third of criteria, depending on the certification system, were assessed. It is possible that a building system renovation would affect some other criteria indirectly, by complicating the project planning process, for example. However, these impacts are rather small considering the inaccuracy of these estimations. The impact of the renovation measure depends largely on the extent of the measure, such as the capacity of a solar PV or heat pump installation. Some of the points can be achieved in these buildings without the renovation. Nevertheless, the shown renovation measures can help achieving points in these criteria in buildings with low-performance building systems.

When doing only a couple of building system-related measures without changing the building envelope, it seems to be the most feasible to choose criteria meant for existing buildings. Even though the renovation should preferably be more extensive than a couple of building system-related measures, the above-mentioned measures provide several points even in the assessment of most criteria focused on large renovations or new construction.

6.3 Suitability and feasibility of a green building rating for a Finnish apartment building

When looking at a comparison of criteria shown in Appendix 1, LEED, BREEAM and RTS GLT include the most criteria and therefore, might form the most comprehensive understanding of the sustainability of the building. However, RTS, Miljöbyggnad and Nordic Ecolabel include the typical concerns of Nordic tenants slightly better, as chemical and moisture risks are taken into account, and the criteria in general are more suitable for Nordic conditions. In addition, Miljöbyggnad is easy to use because of the smaller number of criteria. According to a FIGBC specialist, BREEAM is very focused on the building process, while LEED tends to evaluate the final building and its solutions more (Huusko 2019). It is estimated that 60 % of LEED and BREEAM criteria are similar to criteria in RTS GLT (Huusko 2019). When comparing the certification prices, no very significant differences were to be found in table 4. The assessment cost per criterion is high in LEED, while using Miljöbyggnad as a non-SGBC member is costly. However, the amount of costs is related to how efficiently the process is steered and the charges may rise significantly from those shown.

Nordic Ecolabel seems to be widely known among the public: 91 % of Nordic customers recognize the label and 75 % associate the label with an environmentally-friendly choice (Miljömärkning Sverige AB 2016, 11). Also, according to the CEO of a large housing company, Nordic Ecolabel is well known and valued by Finns in contrast to LEED and BREEAM (Lampela 2018). However, by using Nordic Ecolabel, building system elements would have the least effect according to table 5 and figure 16. The system also demands that the renovation is at least 25 % of the building’s value or envelope area (Ecolabelling Finland 2017, 5) its suitability for building system renovations is questionable: these renovations almost never are this extensive (Nummelin 2019a). These criteria seem to be most suitable for new construction or large renovation projects with envelope-related measures, where Ecolabelled products are used and when marketing to Nordic customers. Miljöbyggnad, in turn, is relatively simple to use but it is not used outside of Sweden and is strongly based on Swedish building code (Strandfeldt 2019), and its feasibility is questionable in Finland, as is even the possibility to pursue a Miljöbyggnad certification.

Both Nordic Ecolabel and Miljöbyggnad seem to be very suitable for new apartment buildings.

This leaves RTS GLT and LEED O+M as the most suitable schemes for Finnish apartment buildings under renovation. RTS GLT might be more suitable for new construction or larger renovation projects than LEED O+M and most probably gives rather low certification points for building system renovation projects (Pekonen 2019). However, RTS GLT is well adapted to Finnish conditions and requirements, in contrast to LEED. In the case of LEED, it is slightly unclear if the most suitable scheme would be O+M: EB or O+M: Multifamily, or if they're the same scheme with only slightly different requirements, because the same criteria document is used. When using only O+M with requirements marked for Existing Buildings, the result is not as suitable for residential buildings, and using Multifamily-marked requirements when available is most probably the solution (Kauppinen 2019a; Pekonen 2019). An inquiry about the use of O+M: Multifamily was sent to USGBC but the answer did not arrive in time to be included in this thesis. BREEAM Bespoke should not be ignored either, especially when it can be tailored to best suit the project. If there is a need to receive international recognition, using an international certification system is, of course, the best option (Pekonen 2019). A summary of the pros and cons of green building certification schemes is shown in the table below.

Table 10. Advantages and disadvantages of green building certification schemes for apartment buildings, mostly when renovating building systems, based on studies, articles, interviews and the writer's conclusions. ([1] Appendix 1; [2] SGBC 2019a; [3] USGBC 2019b; [4] Lampela 2018; [5] Ecolabelling Finland 2018; [6] Ojankoski 2019; [7] Ojankoski et al.; [8] Kauppinen 2019a; [9] SGBC 2015a, 9-24; [10] table 4; [11] Miljömärkning Sverige AB 2016, 11; [12] Strandfeldt 2019; [13] Pekonen 2019; [14] Huusko 2019; [15] table 9.)

	ADVANTAGES	DISADVANTAGES
LEED O+M: EB/Multifamily	■ Extensive assessment [1] ■ Easy to compare buildings worldwide because of same criteria in each country [3] ■ Best option of these four when searching for international investors [13] [14]	■ Not as adapted to Finnish conditions ■ Expensive credit assessment[10] ■ Criteria more commonly used for offices [7] [8] ■ Criteria and documentation in English ■ Not the clearest instructions
RTS GLT (for residential buildings)	■ Well adapted to Finnish regulations and conditions [13] ■ Especially designed for residential buildings ■ Done in Finnish	■ More suitable for large renovations [13] (upcoming criteria for existing buildings can be expected to be more suitable) ■ Very high-performance building systems needed if no envelope measures done [15]
Nordic Ecolabel	■ Well known and valued by future tenants [4] [11] ■ Proof of growing use for apartment buildings [4] [5] → suitable for new apartment buildings ■ Done in Finnish	■ Requires a renovation value of 25 % of total building value → more suitable for large renovations [8] ■ Very small impact of building systems (16 %) [15] ■ Strict material requirements require discipline [4] [6]
Miljöbyggnad	■ Widely used for apartment buildings in Sweden already [2] ■ Allows choosing criteria from two manuals (new and existing buildings) [9] → flexible ■ Fairly straightforward criteria	■ Based on Swedish conditions and regulations (however these are similar to those in Finland) ■ Done in Swedish ■ Not used in Finland [12]

As can be seen in table 10, all of these examined schemes have both advantages and disadvantages, and the most suitable choice depends on the project. When assessing the feasibility of such certifications for apartment buildings, the feasibility of green building in general should be addressed, although this thesis mostly focuses on green building certifications. They are a means of measuring the "greenness" of buildings, and based on an international study (World GBC 2013) green solutions add value to the building according to the following figure.

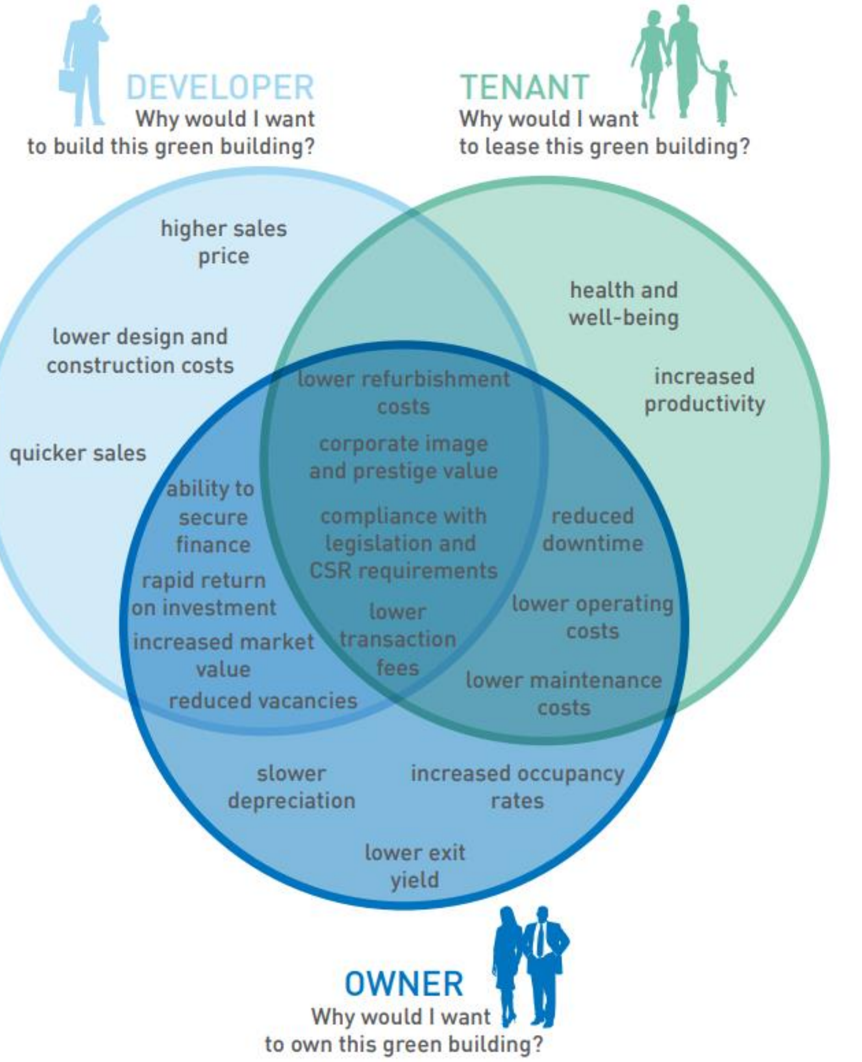

Figure 17. Usually occurring benefits of a green building from the developer's, owner's and tenant's points of view. CSR stands for Corporate Social Responsibility. (World GBC 2013.)

As figure 17 shows, there are several benefits to green buildings for multiple actors. However, some shown benefits, such as lower design and construction costs, depend largely on the project as is stated throughout the study (World GBC 2013), and many of these benefits cannot be assumed to occur in all cases, while most studies show they happen commonly. The same report suggested that the certification level impacts on the upfront costs of a project: buildings with a high rating level (such as BREEAM Very Good or LEED Silver/Gold) had 0-10 % additional costs while buildings with very high levels (such as BREEAM Excellent or LEED Platinum) had additional costs of 2-12.5 % (World

GBC 2013, 21-22). In general, the additional costs of a green building certification are 2-6 % globally, but in Finland most probably just a few percentages due to the good building quality in general (Huusko 2019). However, several studies show that investments will result to lower operating costs, especially in cases of high-performance facades or building systems (World GBC 2013, 19; Knuutila 2017, 20).

The feasibility of a certificate is difficult to measure, but most studies show few downsides to pursuing a green building certificate. A 2015 study examining all LEED certified apartment buildings in USA (in total) and found that the rents in LEED certified apartments are 8.9 % higher in average (Bond & Devine 2015). According to two Master's theses on residential buildings' certifications, pursuing a certification requires that all project parties are well informed about the required measures, the project is efficiently managed and more time is used on planning than in a conventional project. Based on several research papers, the largest challenges related to sustainable building seemed to be higher project costs and the low knowledge of sustainable practices among the contractors. However, the result of the process is usually a high-quality, energy-saving and environmentally-friendly building. (Hedeya 2017, 5; Sandström 2016, 33-34; Knuutila 2017, 62.) In 2014, a Master's thesis found that green building certificates for residential buildings are poorly known in Finland, and in order to add value to this kind of a building by having higher rent or cost to represent the better quality and cover the construction costs, the healthiness, comfortability and lower operational costs of such a building need to be stressed to the buyer or tenant. This is because according to several studies many tenants might struggle finding the value in sustainable buildings by themselves. Similar suggestions were presented in a Swedish thesis from 2013, and that information about the certification in general increases the buyer's interest. (Salomaa 2014, 85-87; Knuutila 2017, 20; Zalejska-Jonsson 2013, 20-24.) But as the environmental awareness has increased during the last years, it can be stated that both the demand for and awareness of certifications has increased. All in all, the overall value of the building seems to increase not only because of the certification itself, but also the improved quality of the building and improved productivity and health of the occupants, but the extent of the increase is unsure.

According to a study conducted in South Korea, the tenants were more interested in buying space that had received a green building certification, but a higher rating level did not necessarily result to higher willingness (Jang et al. 2018). This suggests that even if the impacts of building system renovations can be small as shown in previous subchapter and the building receives a rather low rating, the value of the building increases nearly as much nevertheless. Also, costs can be saved because of the lower costs of projects pursuing a lower rating. Furthermore, several studies have showed that the most significant comfortability factor for apartment tenants is air quality, most probably followed by thermal quality, and even that the correct function of the HVAC systems was an issue also in low-energy buildings (Zalejska-Jonsson & Wilhelmsson 2013; Zalejska-Jonsson 2013, 20-24). These findings suggest that the building systems play an important role, not only when providing better comfortability but also when pursuing higher green building rating.

According to the CEO of a real estate transactions company in Finland, an international investor might not be interested in a property unless it has a green building rating. When searching for funding, choosing LEED or BREEAM will make it easier to find an international investor according to him, and some investors in Finland have also asked about green building ratings when investing on existing buildings. (Huusko 2019.) In Sweden, some landlords have stated that it is challenging to find tenants to buildings without a green building certificate, especially in larger cities. SGBC estimates that such demands will grow in other areas as well. (TIB 2018.) The CEO of a large Finnish housing company stated that the current requirements in certification systems will be the requirements in building code in the future, so the companies not willing to apply for certifications need to do almost the same amount of work nevertheless (Ojankoski 2019). When looking at renovations, combining different renovation measures with mandatory maintenance measures and other possible renovation measures usually make the renovation more cost-effective (Hirvonen et al. 2018, 21). However, small housing companies might struggle with finding financing for the measures nevertheless, and especially certifying with LEED or BREEAM would most probably require an international investor or a real-estate fund regardless of the project type (Kauppinen 2019a). The feasibility of applying for a certification for an existing building is most probably highest when doing an extensive renovation (Ojankoski 2019).

7 IMPACT OF A BUILDING SYSTEM RENOVATION IN CASE BUILDING

This chapter estimates the impacts of an actual planned building system renovation on green building certification points. All the information in this chapter is based on previous chapters, project information and project planning unless mentioned otherwise. Occasionally, definite information is not available and in these cases the made assumptions are presented as well.

7.1 Overview of the case building

The case building is an apartment building built in 1993 and located in Kerava, Southern Finland, accommodating 79 residents in 51 apartments. The building is L-shaped, and both ends of the building have five stories and the middle part of the building has six stories. The northern part (the part of the building pointing to the north) has also an attic floor, and all of the three building parts have a cold attic over the top floor. The gross floor area of the building is 4442 m^2. A plan drawing of the building can be seen in the figure below.

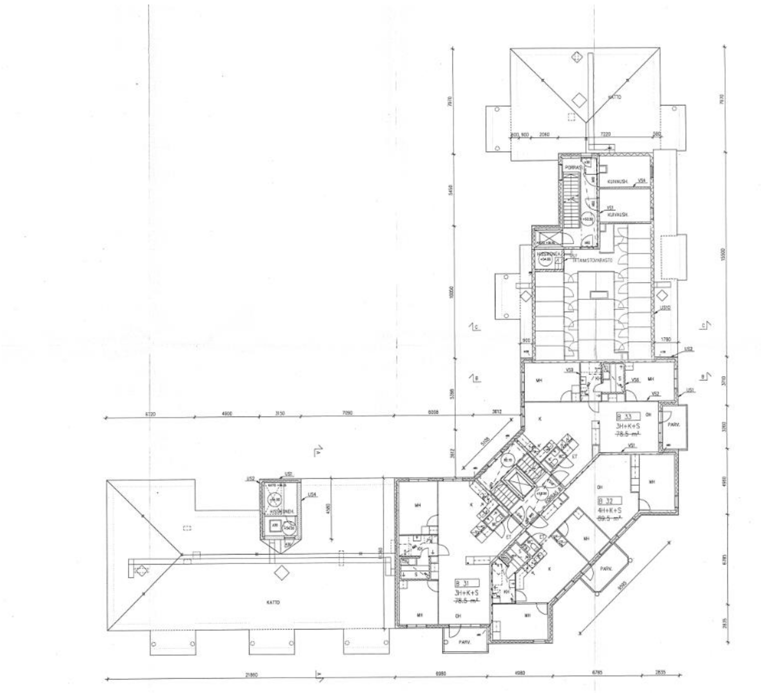

Figure 18. Architectural plan drawing of the 6th floor.

The building's structure is made of concrete and the outer walls have a so-called sandwich structure with a layer of mineral wool enclosed by layers of concrete. The outer surface of the walls is covered partly by painted concrete and partly by ceramic plates. The outer layer of the roof is metal.

Figure 19. Front view of the building.

The U-values of the outer wall and roof structures are lower than 0.22 W/m^2K according to the available documents. Relatively accurate U-values could be estimated by using material information of the different structures. However, typical U-values in table 1 can be assumed to correspond to the U-values of the case building. Other values in table 1 can also be expected to be similar to the actual values in the case building.

A waterborne heating system by district heating and radiators is used in the building. Annual heat, electricity and water consumption data of the building is available from the years 2009-2016, and also monthly data from 2016 can be used in the analyses as well. The figure below presents the energy and water consumption in the building during 2009-2016. The heat consumption is weather normalized and the volume includes the total volume of the building with unheated roof and floor spaces and intermediate floors, which is 12988 m^3.

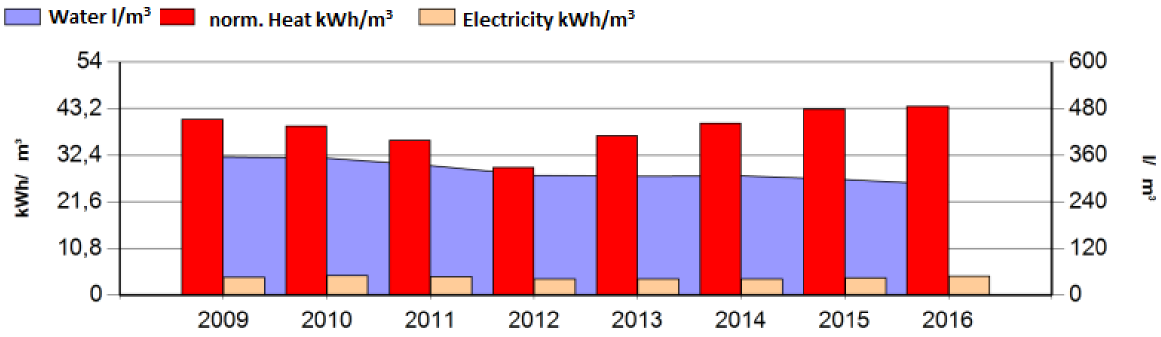

Figure 20. Water, normalized heat and electricity consumption in the case building during 2009-2016.

As can be seen in figure 20, the water consumption has decreased during the recent years, but the normalized heat consumption seems to be increasing after a decreasing period. The E-value of the building (weighted energy consumption as described in chapter 2.4) is 136 kWh/m^{2}a, giving the building a class C in its energy declaration from 2012. However, this outdated calculation did not include household electricity and unlike now, the calculations were based on actual consumption values and the coefficients C_i (eq. 1) were different, and this value cannot be used anymore. If the same E-value was the result of the calculations, the energy class would be D on the current scale (D 1048/2017, 4-23).

The heat used in the building is produced by the local energy company. However, it is estimated that the fuel distribution corresponds to figure 4. The share of renewables is approximately 46 % in district heat production, same is assumed for heat consumption in the case building. The electricity used in the building is produced only by qualified water, nuclear and wind power according to Vattenfall and it is taken from Nord Pool trading market. No information about the average share of nuclear is provided, and it could be assumed, that one third of the electricity is produced by nuclear and two thirds of the consumption is renewable. This is not completely correct as the shares of different production methods vary depending on e.g. weather conditions. Only data about electricity for building systems is available. Hot water use and potable water use are measured in the whole building. The ventilation system in the case building is centralized mechanical exhaust ventilation, and the exhaust outlets are located on the sixth floor and the attic floor. The following table presents the air flows from all of the exhaust outlets in the building which have an own roof exhaust fan. The table shows the air flows during normal operation and boosted operation.

Table 11. Exhaust air flows in the case building in the two modes of the system. Part 1 in the first column means the southern and middle part of the building, while part 2 means the northern part.

Floor, part	Exhaust no.	Normal (dm^3/s)	Boosted (dm^3/s)
Attic, 1	1	540	810
Attic, 1	2	670	995
Attic, 2	3	600	900
Attic, 1	4	80	160
Attic, 2	5	60	120
6th floor, 1	6	15	45
6th floor, 1	7	20	60
Attic, 1	8	15	45
Attic, 1	9	20	60
6^{th} floor, 2	10	15	45
6^{th} floor, 2	11	20	60
total (all)		2 055	3 300
total (3 largest)		1 810	2 705

After constructing the building in 1993, only quite minor alterations have been made in the building, such as changing the heat exchanger in the plant room and adding glazing to the terraces. All in all, the apartment building is a quite typical example of a Finnish apartment building built during 1976-2002 and represents this building class rather well. Therefore, it is suitable for examining the impacts of a building system renovation.

7.2 Tentative renovation measures

The renovation process begins with project planning as described in chapter 3.1. The renovation process is still at this stage: the most suitable, feasible and energy-saving measures are defined by doing calculations, following a similar process flow as in figure 7. After collecting information about the building and its building systems and analyzing the possible measures, the most suitable ones are dimensioned and their impacts on e.g. energy consumption are calculated. All the measures presented are tentative, since during the writing of this thesis there are many uncertainties about the actual feasible measures in the case building. The actual measures as well as the impacts of these measures can be estimated only after dimensioning, which will happen after the completion of this thesis.

Many different building system solutions can be added to increase the energy efficiency and sustainability of a heating system in an apartment building, but there are many aspects that have to be considered when choosing the optimal solution. From a legal point of view, the purchased energy has to be 130 kWh/m^2 or lower or the E-value has to be reduced to 85 % or less of the current E-value (D 4/13), which is 115.6 kWh/m^2, although calculating the current E-value should be done instead of using the 2011 value which does not consider household electricity. A building permit is also needed. Based on chapter 2, buildings similar to the case building often have problems with inadequate supply air flow and the indoor air quality could be improved, which shows that adding mechanical supply air system with heat recovery to reduce energy use would probably result to the best final state. However, many extensive measures like this and e.g. upgrading all water pipes, ducts and sewers, could not be considered for the building because of their low cost-effectiveness. Beyond the renovation measures presented in several studies and compiled in chapter 3.2, some additional measures were considered for the case building. For example, installing apartment-specific temperature measurement devices and using them for controlling temperatures and having motion-controlled exhaust fans were considered. However, because no extensive piping changes are planned for the building, these measures are less cost-efficient. The former would be more useful if a mechanical supply air ventilation system was installed and the latter requires apartment-specific exhaust fans for proper function instead of the centralized exhaust ventilation system. Also electric drainpipe heating cables are most probably installed to prevent icing in drainpipes – these would not necessarily improve the energy-efficiency of the system, but they could be used for demand response. They would also improve safety as there is no risk of ice falling and no need to remove snow. It is important to ensure the cables are on only when needed, and they are usually automatically controlled by outdoor temperature.

Based on figure 20 the heat consumption is increasing and based on table 11 the three largest exhaust flows account for approximately 88 % of the ventilation heat losses during normal operation, which shows that there is great potential in energy-efficient heating solutions utilizing exhaust air – an EAHP using CO_2 as refrigerant. EAHP is seen as an effective way to lower the primary energy use, increase the share of renewable energy consumption in the building and the use of CO_2 as refrigerant lowers the environmental impacts significantly and according to chapter 3.3.1, most common other refrigerants are soon banned in new products. Furthermore, by using CO_2 as refrigerant, the refrigerant pipes require less space and the COP of the whole EAHP system can be estimated to be 4-4.6, when both DHW and radiators are heated (Jokinen 2019). A GSHP would be more expensive yet it is still an option, if the EAHP proves to be an improper solution.

The option of adding solar PV is relevant as the electricity use increases in the building when installing an EAHP. The cost-efficiency of this measure is questionable, especially because almost one third of the electricity costs are uncorrelated with the electricity consumption and the produced electricity can currently not be used in households. However, at least the increased consumption has to be covered and the installation could also be used to charge electric cars later. If the produced PV electricity is mostly used for electrified heating solutions, the electricity demand peaks occur generally during times when the least heating is needed, which lowers the cost-effectiveness of the PV installation. In order to do dimension the PV system properly, so, that the production exceeds the current electricity consumption in the building as rarely as possible, hourly electricity consumption data should be obtained. It can be approximated that a 20 kW_p solar PV installation can be installed on the south-facing roof area of 150 m^2, as this installation would require 120-150 m^2 (Motiva 2018d). Although the building is estimated to already have some LED lighting systems with timers or pecu switches (light level sensors), all lighting systems in common spaces are assumed to be upgraded to motion-controlled LED lighting in order to save energy but also increase comfortability and safety. In reality, different control methods are suitable for different lighting groups in apartment buildings (Rautkylä & Pasanen, 9), but the energy-saving potential is similar nevertheless and the actual control methods do not have to be specified for the purposes of this thesis. When it comes to the drainpipe heating cables, their dimensions are unknown but their electricity use is quite low, which is why no dimensions are estimated yet. Also other metering systems and BAS, e.g. demand response applications, are probably installed.

The actual dimensions of the planned measures can only be roughly estimated for the purposes of this thesis. The planned measures with their initially planned specifications and impacts on consumption values are collected to the table below. The values in third column are calculated in Appendix 10.

Table 12. Tentative renovation measures in the case building. NB! No electricity or primary energy savings values take household electricity use into account.

MEASURE	SPECIFICATIONS	IMPACTS ON CONSUMPTION VALUES
EAHP with CO_2	System COP 4.3	Assumed to decrease district heating use by 70 % (by 348 MWh) → electricity use in common spaces increases by 160 % → primary energy use decreases by 58 %
Solar PV panels	20 kW_p, direct installation on roof	Decreases electricity consumption in common spaces by 14 000-20 000 kWh/a (latter value chosen because of southern location)
Motion-controlled LED lighting	In all common spaces	Assumed that half of systems already updated, and the electricity consumption reduction is half of that in table 9: 6 %
Drainpipe heating cables	-	Increases electricity consumption slightly

After reaching consensus on the renovation measures and creating the project plan, the planning process starts. Although the plans are only tentative, some remarks on the renovation phase are presented next. Because of the ongoing government change, it is not yet known if subsidies are available for the project. The outcome will affect the LCC of the renovation.

The inner roof is a continued space through the whole building, making it easier to install pipes for EAHP without making holes in the inner roof structure and compromising the air and water compactness of the building. The refrigerant pipes can be lead on the inner yard's side to prevent any shortcomings in appearance of the façade. While the CO_2 refrigerant piping needs less space, the cycle requires higher pressure than in a glycol-refrigerated system. The existing fuses seem to allow an EAHP installation, i.e. the increase of needed power. The PV panels could be installed directly on the south-facing roof areas, as the roof already has a 22° angle which does not differ significantly from the typically optimal 15° (Nummelin 2019b). This part of the roof does not either have any exhausts or other installations blocking the radiation.

The aim of the renovation is to also use prefabricated solutions, because they are proven to make the building process more efficient also in the case of building systems. When actual decisions on prefabrication are made, measurements need to be done on-site in order to be certain about e.g. the pathway sizes in the building. The largest problem with prefabricated elements in this case is the small manholes and doorways, making the transfer of large combined elements difficult. For example, several boilers with sizes of 800-1000 liters are needed. However, they are most probably relatively long and not as wide in order to have proper vertical temperature differences, making it easier to transfer them without having to demolish any walls or doors. (Nummelin & Jokinen 2019.). When using these solutions, more planning is required compared to conventional methods while the installation time is shorter.

When aiming for receiving a green building certification in a residential building, the construction (or renovation) process requires changes according to a Master's thesis (Knuutila 2017). This thesis also presents a process chart for following the needed steps in the certification and building process. According to two Master's theses on residential buildings' certifications, pursuing a certification requires that all project parties are well informed about the required measures, the project is efficiently managed and more time is used on planning than in a conventional project. Based on several research papers, the largest challenges related to sustainable building seemed to be higher project costs and the low knowledge of sustainable practices among the contractors. However, the result of the process is usually a high-quality, energy-saving and environmentally-friendly building. (Hedeya 2017, 5; Sandström 2016, 33-34; Knuutila 2017, 62.) Based on experiences in Finland, planning and sourcing requires more time and effort, and on the construction site it has to be assured that subcontractors use the agreed materials (Ojankoski; Knuutila 2017, 20). It is instructed to conduct energy-efficiency assessments and pay attention to certification requirements in a very early stage of the project as well as be sure all the needed documentation can be provided (Kauppinen 2019c). Therefore, if there were interest in applying for a certificate during this renovation process, initial assessments on whether it is possible should be conducted first, before continuing with the certification process according to chapter 4.3.

7.3 Possibilities of receiving a green building certification

This chapter aims at estimating the possible points the case building could receive when doing a green building certification assessment in order to do an initial assessment of the potential and in order to see the possible point improvements due to the building system upgrade. The estimates are done both for the existing building in its current state as well as for the building under renovation.

In order to make more accurate assessments, not all four certification systems considered in the empirical part are used in the assessment for the case building, and based on table 10, some of them are not even suitable for the case building or its planned renovation. Miljöbyggnad is excluded because of its irrelevance in Finland and Nordic Ecolabel is excluded because of the renovation scope requirement of 25 % and small impact of a building system renovation according to table 5. Therefore, LEED O+M: EB/Multifamily and RTS GLT will be used in the assessments for the case buildings. However, RTS GLT is not suitable for existing buildings and a building system renovation might give low points according to tables 5 and 9. BREEAM should not be completely ignored in actual certification considerations, because a tailored set of criteria is of course more suitable, while it is probably more expensive.

Full assessments cannot be made within the scope of this thesis. The points are simply estimated, and proper certification point calculations would require for example energy simulations, LCC calculations and many measurements and expert consultation. Unfortunately, only the criteria directly affected by building system renovations are chosen for more intricate assessments because the project has not yet started. Evaluating the renovation process as a whole would cause even greater uncertainties in the assessment as there is no data on the actual course of renovation. Furthermore, there is not enough data about the building in its current state. Although the criteria not directly related to building systems are excluded, the remaining criteria are not easy to assess either: criteria focusing on energy and HVAC are called “complex credits” by LEED because they require more time and effort for assessment (USGBC 2019g). This indicates the limited possibilities of calculating exact points related to these credits. The made calculations are shown in Appendix 10.

LEED O+M criteria include requirements that need to be filled directly (establishment requirements) and requirements that need to be filled regularly during operation (performance requirements). The performance period for performance requirements has to be between 3-24 months and the periods in different criteria have to overlap. (USGBC 2013, 12.) Values from previous years or estimated consumption values for the following years are used for performance requirement assessments.

7.3.1 As an existing building

The green building certifications for existing buildings mostly focus on the maintenance and administration of the building. In its current state before the renovation, the building could tentatively pursue a LEED O+M: EB/Multifamily certification. In Sweden, a Miljöbyggnad certification would most probably be suitable. The following table shows the point estimations of building system –related criteria with most relevant comments.

In order to better understand the point estimations, it is recommendable to familiarize oneself with LEED O+M criteria (USGBC 2018) and guidance (USGBC 2013).

Table 13. Estimation of points in LEED O+M:EB before the renovation (USGBC 2018). When requirements differ between EB and Multifamily, the requirements for Multifamily are used. As there are almost no performance requirement differences between EB and Multifamily, the results are quite similar when using EB. A line in the column "Points" indicates, that the points could not be estimated.

CRITERION	WEIGHTING	MAX. POINTS	POINTS	COMMENTS
Indoor water use reduction	4.5 % (also required)	required + 5	fulfilled + 5	The total water use in plumbing fixtures has to meet a baseline: e.g. in toilets 9 liters/flush – the current toilets use maximum 6 liters/flush (Kuluttajaliitto), the same 33 % reduction assumed in total use
Building-level water metering	required	required	fulfilled	Potable water use meters exist, monthly data recorded
Cooling tower water use	2.7 %	3	-	No cooling towers in the building
Water metering	1.8 %	2	0	Water metering in at least 2 systems required
Minimum energy performance	required	required	unfulfilled	No need to calibrate the energy meters as they are owned by the energy provider; the energy use is 6 % lower than in comparable buildings (assumed to be apartment buildings of same age), when 25 % is required
Building-level energy metering	required	required	fulfilled	Energy consumption is metered
Fundamental refrigerant management	required	required	fulfilled	No CFC is most probably used in the HVAC systems as the use has been banned for a long time
Optimize energy	18.2 %	20	0	Energy use should be improved by at least 26 %

performance				
Advanced energy metering	1.8 %	2	0	None advanced meters installed
Demand response	2.7 %	3	0	No required demand response actions existing
Renewable energy and carbon offsets	4.5 %	5	2	The energy contract is assumed to be in place for minimum two years, and 47 % of energy is assumed to be renewable (1.92 points)
Enhanced refrigerant management	0.9 %	1	1	No refrigerants (cooling) used in common spaces, refrigerants with ODP > 0 and GWP ≥ 50 most probably not used in households
Minimum indoor air quality performance	required	required	fulfilled	The building does have operable windows in bedrooms and living spaces, however meeting ventilation requirement values unclear because reference values unclear, but assumed to be fulfilled
Enhanced indoor air quality strategies	1.8 %	2	1	Entrances can be assumed to have entryway systems, e.g. mats with grates (a common practice in Finland), weekly maintenance assumed; reference values for supply air quality cannot be accessed
Thermal comfort	0.9 %	1	1	In bedrooms and living spaces: the occupants can control the space temperature to some extent, and it can be assumed that the windows have blinds and at least one operable window, but humidity control uncertain
Interior lighting	0.9 %	1	0	Requires lighting quality measurements that cannot be conducted
total	**41 %**	**45 (6 req.)**	**10 (5 req.)**	

In order to receive a certification, the case building should fill the 12 obligatory criteria in LEED O+M. The energy performance of the current building is too low to even be considered for a LEED certification. It is clear that the building cannot reach any certification level in LEED. In the case of existing building, 2016 is used as a reference year as the performance period is often 12 months. This year had very high values compared to the previous years.

Points from criterion Renewable energy and carbon offsets are unsure, as whether certain fuels largely used in district heat production should be defined as renewable. In this case, waste heat, forest fuel (wood), industry wood waste and other biofuel were assumed to be renewable, while peat was not included, forming 46 % of the heat production. Furthermore, as the points include fractions, it is unsure whether points are rounded up or down.

7.3.2 As a building undergoing renovation

The points in RTS GLT and LEED O+M: EB are estimated for the case building under renovation. Applying for a Miljöbyggnad certification would be the most suitable if the building was located in Sweden. The tables below show the estimations for criteria that are directly related to building systems and shows comments in more unsure situations. The first of the following tables refers to table 13 in many cases in order to prevent repeating same information. In the case of PV panels, the higher values in table 12 are chosen to be used because the case building is located in Southern Finland. For clarity reasons it was assumed that PV electricity could be used entirely in the building, which most probably requires a battery of some sort. In order to better understand the point estimations the following tables, it is recommendable to familiarize oneself with LEED O+M criteria (USGBC 2018) and guidance (USGBC 2013) and RTS GLT guidance (RTS 2019a).

Table 14. Estimation of points in LEED O+M:EB/Multifamily after the renovation (USGBC 2018). When requirements differ between EB and Multifamily, the requirements for Multifamily are used. As there are almost no performance requirement differences between EB and Multifamily, the results are quite similar when using EB. A line in the column "Points" indicates, that the points could not be estimated.

CRITERION	WEIGHTING	MAX. POINTS	POINTS	COMMENTS
Indoor water use reduction	4.5 % (also required)	required + 5	fulfilled + 5	No water-saving measures planned, see table 13
Building-level water metering	required	required	fulfilled	See table 13
Cooling tower water use	2.7 %	3	-	No cooling towers in the building
Water metering	1.8 %	2	0	Apartment-specific metering or other water metering not planned to be installed – see table 13
Minimum energy performance	required	required	fulfilled	Energy consumption 55 % lower than in comparable buildings, 25 % required
Building-level energy metering	required	required	fulfilled	Energy consumption is metered
Fundamental refrigerant management	required	required	fulfilled	See table 13 ; Only CO_2 used in EAHP
Optimize energy performance	18.2 %	20	20	Energy consumption 55 % lower than in comparable buildings
Advanced energy	1.8 %	2	0	Energy meters should record and store energy use data hourly for minimum 36 months and energy data reported to customers; but it is

metering				not feasible in older buildings (Möttönen et al. 2013) and most probably not installed
Demand response	2.7 %	3	1	Some demand response applications installed, so one point is estimated to be received
Renewable energy and carbon offsets	4.5 %	5	5	All energy produced on-site and 48 % of purchased energy is renewable; unclear, whether recovered heat is considered renewable; if it is, 5 points, if not, 3 points
Enhanced refrigerant management	0.9 %	1	1	See table 13
Minimum indoor air quality performance	required	required	fulfilled	No changes to supply ventilation planned, see table 13
Enhanced indoor air quality strategies	1.8 %	2	1	See table 13
Thermal comfort	0.9 %	1	1	See table 13
Interior lighting	0.9 %	1	0	Requires lighting quality measurements and improvements in households as well, so the lighting upgrades do not affect, see table 13
total	**41 %**	**45 (6 req.)**	**34 (6 req.)**	

Table 15. Estimation of points in RTS GLT for residential buildings after the renovation (RTS 2019a). A line in the column "Points" indicates that the points could not be estimated.

CRITERION	WEIGHTING	MAX. POINTS	POINTS	COMMENTS
Y1.1 Life cycle carbon footprint	6.4 %	7	6-7	A complete life cycle carbon footprint assessment required for all life cycle phases; a 37 % reduction to comparable building estimated
Y2.1 Energy efficiency	7.3 %	8	2.5-3.5	Rough approximation of E-value: 135 currently (class D), and 104 after the renovation (class C)
Y2.2 Measuring energy use	2.7 %	3	1.5	It can be assumed that the building has a good-quality measurement system integrated to BAS (although this is unsure); 1.5 points more could be achieved if energy consumption was reported to occupants in real-time
Y2.4 Efficiency of systems	1.8 %	2	2	Lighting and drainpipe heating systems most probably chosen to be very energy-efficient
Y3.1 Efficiency of water use	2.7 %	3	0	No apartment-specific water metering planned to be installed
S1.1 Thermal conditions	5.5 %	6	-	Passive cooling opportunities should be assessed, Operative temperature has to be at least in accordance with the building code, ensuring requires simulation or measurements!
S1.2 Indoor air quality	6.4 %	7	0	Not enough information to determine if replacement air flow is adequate; the air change rate is 0.5 1/h, when 0.6- 0.7 1/h is required, exhaust air flow in range hoods not adequate either
S1.3 Opportunities for occupants to make adjustments	1.8 %	2	0.5	In bedrooms and living spaces: the occupants can adjust the temperature in the winter and at least one window can be opened, but no dimming for lighting will probably be installed

S2.2 Quality of lighting	1.8 %	2	0	Cannot be estimated if specific lighting quality values are filled in households
Total points (weighting)	**36 %**	38	12.5-14.5	

Based on table 14, the renovated building fulfills all the 12 obligatory criteria related to building systems and receives a quite high percentage of available points, showing that a LEED O+M certification could be achieved with the performance values. Table 15 shows that in RTS GLT not as high a share of available points is achieved.

Not enough information was available to do complete estimations. Estimating the values especially for the construction and demolition phases would have caused too much uncertainty as more expertise for value estimations or even measurements would have been needed. However, both the E-value and life cycle carbon footprint are clearly improved after the renovation because of the high energy savings values. In LEED, meeting the ventilation requirements was unsure because viewing the reference values was subject to a charge. The actual E-value can be very different because of household consumption estimations and net heated area estimations. However, the change in E-value is more accurate than the values itself.

7.4 Impact of the renovation

The expected impacts of the tentative renovation measures are discussed in this chapter. The feasibility of applying for a green building certification is discussed shortly as well.

7.4.1 Impacts of renovation measures

The estimation of results of renovation measures is shown in the figure below.

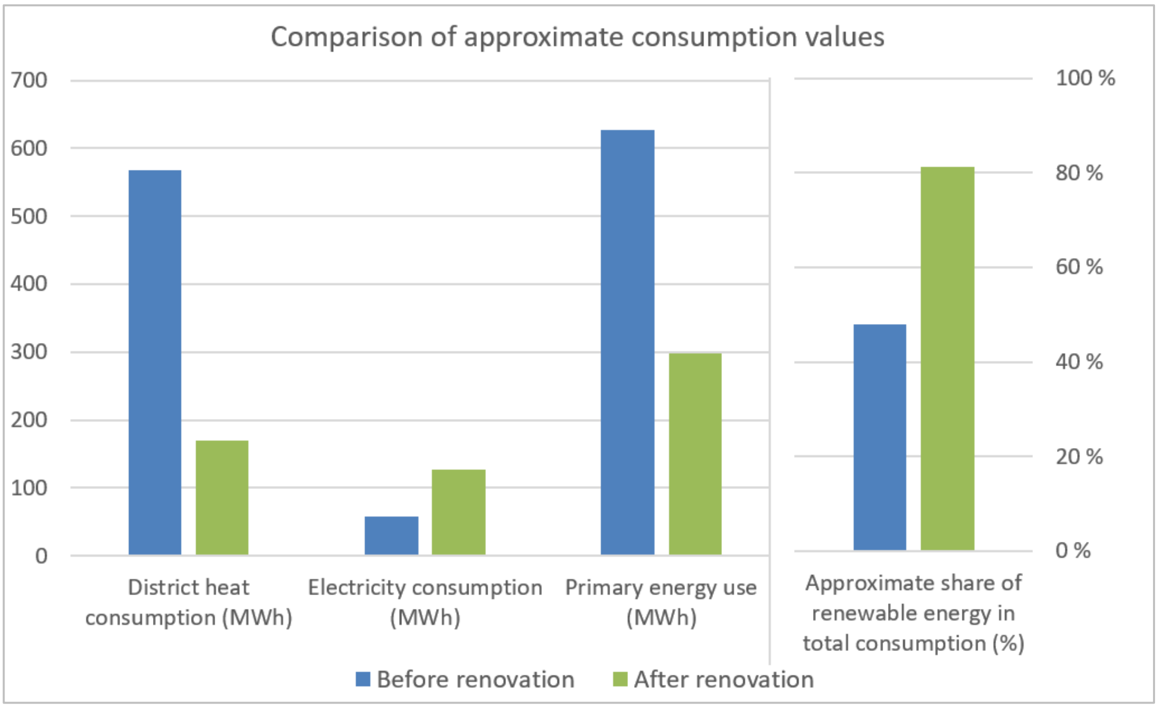

Figure 21. Annual energy consumption values and renewable energy share before and after the renovation measures. The values do not take household electricity use into account.

Figure 21 shows how the energy consumption would decrease by a half and the share of renewable energy use would increase to over 81 %, reducing the emissions of building use significantly if the measures described in chapter 7.2 were executed. The rest of the energy use consists mostly of nuclear energy, which also is carbon-neutral but not renewable. No information about household electricity use was available. The renewable energy share of energy consumption could be further increased by encouraging the tenants to use electricity from renewable sources and switching to entirely renewable electricity in common spaces. The electricity used for the drainpipe heating cables was not included, and the total electricity use would therefore, be slightly higher than in figure 21. Other inaccuracy factors related to estimations in calculations are, however, as notable as this consumption increase.

The bought energy consumption or primary energy consumption as shown in figure 21 is estimated to decrease by 53 %. This would significantly lower the operational costs during the lifetime of the building. However, these values are only estimations. When comparing the calculation results to typical values, the energy-saving potential of EAHP might be slightly overestimated. However, an existing EAHP with a COP of 4.64 was used as reference. Also, not all of the produced PV electricity could probably be used in the building during peak production and some of the produced electricity would probably have to be sold to the grid or stored in a battery of some kind. The previously calculated E-value, or energy consumption values for that matter, did not take electricity used in households into account, which makes any consumption comparisons and change estimations more difficult.

When looking at the chosen renovation measures critically, the EAHP provides as much heat year around, in practice possibly slightly more during warmer weather. During this time, space heating is not in use and the heat demand is only approximately 25 % of the usual demand, since now only DHW is heated. The supporting heating method after the renovation, district heating, can be cheapest to be utilized during summer in Finland (Helen 2019). This makes using EAHP more unprofitable in warm weather conditions. However, the pricing systems of district heating depend on energy companies and the pricing in this building does not seem to change depending on the seasons (Keravan Energia 2019). The electricity production of the PV panels is heavily focused on the summertime, when the EAHP might not be used and in any case the electricity demand of the building is at its lowest, unless a cooling function is used. This lowers the profitability of the PV installation. When it comes to the installed LED lighting systems, they can also improve the illumination levels by 50 % (Rautkylä & Pasanen, 12-13.) adding comfortability and safety, but the building is already estimated to have some LED lighting, reducing this impact. Because of the changes in the building systems, changes in maintenance measures and plans in the building will also occur and need to be noted. For example, the filters of an EAHP need regular maintenance and changing (SULPU). The proper joint operation of the energy systems and the added BAS needs to be ensured regularly.

7.4.2 Impacts on receiving a green building certificate

The impacts of the renovation can be estimated by comparing the point scores in chapter 7.3. The following figure presents the estimated points for the case building both before and after the renovation measures described in chapter 7.2.

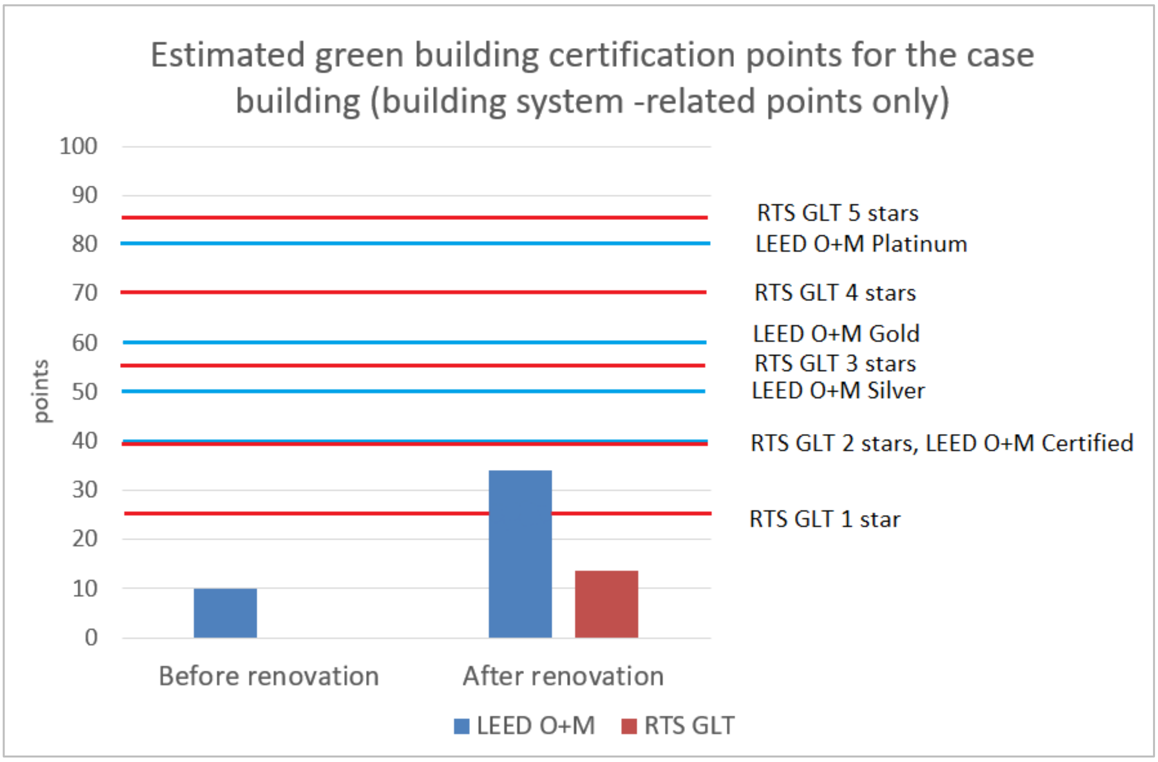

Figure 22. Estimated points for the case building in LEED O+M: EB/Multifamily and RTS GLT. The total points needed to achieve certain certification levels are also illustrated as lines. Obligatory criteria are not taken into account in this figure, but they need to be fulfilled as well.

When comparing the point scores before and after the renovation, the change in LEED O+M score was 24 points, which means an increase of 240 % when looking at the assessed criteria only. As tables 2, 13 and 14 show, only six more points are needed to reach certification level LEED O+M Certified. The change in RTS GLT cannot be assessed, since the criteria for existing buildings are not available yet and the used criteria are not suitable for existing buildings. The share of fulfilled building system -related points before the renovation was 22 % (LEED O+M) and after the renovation 76 % (LEED O+M) and 33-38 % (RTS GLT). If these shares would remain unchanged when assessing the complete criteria, the reached classes after renovation would be LEED O+M Platinum and 1 star in RTS GLT according to table 2. However, because the structure of the building is not renovated, the share is not likely the same and it is still unsure whether the building could fulfill also the six obligatory requirements not related to building systems in LEED O+M and receive enough many points to receive a certification. To prove this, the entire building should be assessed. In any case, it is clear that a building system renovation can has a significant impact on the scores of this building.

In this case, the 20 points from criterion EA Optimize energy performance could have been obtained by “only” a 45 % energy consumption reduction compared to similar buildings, when in this case, it was estimated to be 55 %. However, if household electricity was included in this criterion assessment, the reductions would change from 6 % to 5 % (existing building) and from 55 % to 46 % (renovated building). These changes would not change the received points. There could even be possibilities for receiving points in the Innovation-categories (weighting up to 5 % in LEED O+M, 9 % in RTS GLT) due to e.g. the rather new-found method of using CO_2 in EAHP.

The certification charges can be estimated as well based on table 4. The estimated prices are shown in the table below. This is only the partial cost, especially in the case of LEED, because receiving a certificate would require assessing more criteria than the building system –related criteria and additional costs often occur.

Table 16. Comparison of partial certification charges for the case building, when 16 criteria are assessed in LEED.

	LEED O+M: EB/Multifamily	**RTS GLT**
Application	1320 €	2294 €
Certification	1980 €	3658 €
Other costs	2112 € (3 complex criteria) 5720 € (13 other criteria)	Calculation tool license, for e.g. five years: 930 €
total costs	11 132 €	6 882 €

Table 16 shows that certifying with LEED would be clearly more expensive compared to RTS GLT. The high expenses of energy-related criteria (complex criteria) in LEED are distinct. Some criteria do not apply to the case building and do not provide points in almost any case, such as WE Cooling tower water use, and these should not be assessed unnecessarily. The costs in table 16 are relatively low and do not create a large risk for a medium-sized or large housing company. Furthermore, based on chapter 6.3, there are many advantages to applying for a green building certification in an apartment building. Suitability of the upcoming criteria RTS GLT for existing residential buildings should be assessed, and it is possible it could be more suitable for the case project than the used criteria for new or largely renovated apartment buildings. All in all, a larger renovation with envelope measures seems to broaden the possibilities of receiving a green building certification currently, and the suitability of Nordic Ecolabel should be assessed if the renovation project value was at least 25 % of the building value, because it is likely be the clearly best known certification system among potential tenants (Miljömärkning Sverige AB 2016, 11). If a certification was to be applied for, the renovation should be planned well, as explained in chapter 7.2, and the added value should be clearly advertised to the possible tenants. LEED O+M or the upcoming RTS GLT for existing buildings would be the most suitable. However, also the current RTS GLT criteria could be well used in Finland to steer the project to reach a better sustainability value (Pekonen 2019).

7.4.3 Impacts of prefabrication

The advantages and disadvantages of prefabricated building systems were discussed in chapter 3.4. In LEED O+M and RTS GLT criteria related to building systems (analyzed in tables 5 and 6) not much direct impact of prefabricated systems can be seen and indirect impacts are difficult to estimate. Only in RTS GLT criterion Y1.1 Life cycle carbon footprint using less materials and materials with lower unit emissions for the new building systems and reducing emissions in construction phase would help receiving maybe one point. Because the benefits are largely connected to the construction phase instead of operational aspects, the certification benefits are presumably most clearly seen in certification schemes for new buildings or buildings facing an extensive renovation. However, when viewing the complete criteria of these two certification schemes, it is certain that because prefabrication increases safety and reduces material use, costs, waste, transportation and project time, it has an impact on the final certification points, when a project with prefabricated solutions were to apply for a certification. Most of the criteria in LEED O+M category Materials and Resources are impacted by prefabricated solutions, and they account for 17 % of required criteria and 7 % of total the points. The criteria in LEED O+M, especially the criteria in the above-mentioned category, require mostly plans and policies, and these are simpler to make when purchasing prefabricated solutions and not separate parts because product tracking is easier. As estimated, 20 % of RTS GLT criteria are related to construction phase efficiency, materials, LCC and carbon footprint that can be affected by prefabricated solutions. Always when estimating maximum points, innovation-related criteria should not be ignored. However, these percentages represent the criteria that prefabrication can affect. With more intricate assessments the impacts of prefabrication would probably be found in some other criteria as well.

When going through the entire criteria in certification schemes for this renovation, prefabrication would most probably have an impact on waste-, safety- and LCC-related criteria in LEED and RTS GLT. In conclusion, prefabrication would help this project to achieve some points, but the impacts are more clearly seen in larger renovations or new construction and the impacts can be seen in several criteria. The impact of prefabrication in other certification systems should also be assessed.

8 CONCLUSIONS

The aim of this Master's thesis was to estimate how a building system renovation could affect green building certifications in apartment buildings built during 1976-2002. The small scope of a building system renovation was a slight problem when searching for suitable certification schemes. The scope of the renovation is always different and therefore, the applicable certification system and the achieved certification points depend greatly on which renovation measures are executed and what processes are included in the renovation. Adding building envelope measures to the project would increase the selection of suitable certification schemes largely. They were not usually cost-efficient for these buildings, and eliminating them makes schemes for existing buildings more suitable.

From a sustainability point of view, these certifications could be seen as incentives to increase the environmental performance of buildings, and because of the high energy consumption of existing buildings, it should be made certain that applicable certification systems would be available for existing buildings as well. The lower cost of doing only building system –related measures should be taken into account by not necessarily demanding envelope measures, as is done in most certification systems. Currently, only LEED O+M seems to be entirely applicable and functional for Finnish apartment buildings under building system renovation, and even in LEED's case, not enough information about LEED O+M: Multifamily was available. The upcoming RTS GLT for existing residential buildings is most probably a suitable certification system for many buildings included in the scope, but it is unsure if it could also be used for building system renovations. Nordic Ecolabel seems to be the most suitable certification system for residential buildings when thinking of the market potential, considering how well it is known among the public (Miljömärkning Sverige AB 2016, 11) and how it focuses on healthy indoor air and safe and environmentally-friendly materials. Its certification criteria for repair construction are somewhat inflexible because of the 25 % scope requirement and the fact that all criteria need to be filled in order to be certified. This can also be a positive feature, granting the sustainability of the certified building in a broader sense. For smaller renovation projects fulfilling all the requirements might be difficult. Miljöbyggnad, on the other hand, allows choosing most fitting criteria between criteria documents for existing buildings and buildings under renovation, making it more flexible and suitable for building system renovation projects. In order to increase the use of green building certifications for apartment buildings undergoing renovations of technical systems in Finland, the possibility to allow similar flexibility should be assessed. This could be done for example with the existing RTS GLT criteria for residential buildings that are built or extensively renovated and the upcoming criteria for existing residential buildings. RTS GLT could also be effectively used for simply steering the project, but the certification itself is not of course be used and thus, the market value is not necessarily improved (Pekonen 2019). Whether only doing a building system renovation would result to receiving a green building certificate is unsure. For apartment buildings with a more insulated building envelope and even mechanical supply ventilation system the answer is probably positive.

The results can quite well be extrapolated to the building stock. A building system renovation similar to the planned for the case building could reduce the bought energy consumption in the building by 43 %, when assuming typical and unchanged household electricity consumption according to chapter 2.4. When assuming that the share of total residential energy use in apartment buildings is the same as heating energy use (25 %, chapter 1), that this building stock forms a similar share of total apartment buildings as apartments do (34 %, chapter 2) and that buildings account for the same energy consumption in Finland as in EU (40 %, chapter 1), doing this kind of a renovation in each building in this building stock would reduce the energy use in Finland by 1.5 %. Because this kind of a renovation has a significant impact on renewable energy shares and produced emissions, there would notable be impacts on Finland’s energy and climate targets shown in figure 1. Furthermore, all of the results in this thesis are calculated using typical heating energy consumption values in Southern Finland and in the north the absolute energy savings can be up to 30 % higher. However, not all buildings have the same initial values as the case building or an average building.

The chosen approach for defining the applied renovation measures was finding the renovation measures estimated to be most cost-effective and energy-saving. Choosing building system renovation measures that improve the indoor air quality would result to higher certification point scores based on assessments in chapters 6.2 and 7.3. As awareness of social and environmental sustainability aspects can be estimated to increase, choosing measures improving the indoor environment and reducing emissions will probably gain more importance when choosing renovation measures. This would increase the possibilities of receiving green building certifications during renovation projects. However, the certification systems are updated continuously and as the building codes seem to become more and more stringent, the same progress will probably be witnessed in certification criteria requirements. Applying for certifications encourages making choices that might become involuntary in the future as suggested by Ojankoski (2019). The Finnish Ministry of Environment does indeed aim at e.g. including carbon footprint calculations and emission limits in the Finnish building code during the next decade (Rakennustuoteteollisuus 2019).

It is clear that estimating or calculating certification points as accurately as possible is time-demanding and requires consulting different specialists as well as conducting surveys, for example. Also, the extent of the assessments is large when assessing entire buildings or projects and their management, and expertise is needed to make even educated guesses. One problem related to certifying existing buildings is the lack of needed documentation. The amount of documents needed for applying a certification depends on the certification scheme. The case building data, for example, lacked information on calculated U-values of the structure components and information on household electricity consumption. When constructing new buildings it is easier to incorporate the required methods for receiving a certification, such as documentation and choosing only sustainable materials.

The energy savings estimated for heat pumps seem to be quite high, and it is clear that even with lower energy consumption reductions many points are possible to achieve. However, the increased electricity consumption when installing a heat pump has a rather negative impact on E-value calculations, thus, on points from RTS GLT and Nordic Ecolabel assessments. In reality, the electricity can be produced with renewable sources, lowering the environmental impacts compared to the initial state where district heating, which is rarely produced with entirely renewable sources.

Both prefabrication and building according to certification requirements require more time, effort, planning and precision in the renovation process and the benefits become more visible over time, but it seems that they are both becoming more common. The impacts of prefabrication in green building certifications is difficult to assess because of the broad influence prefabricated solutions have on the building or renovation process. The impacts should be assessed through several renovation projects or intricate calculations in order to have trustworthy data. Several courses of estimations and assumptions make the final results quite inaccurate. The point estimations for the case building are more accurate than the estimations in table 9 because not as much initial data had to be estimated. However, there can be errors in the energy consumption calculations also because of possible calculation mistakes, and with LEED, it was occasionally uncertain whether energy use in households was to be included and whether recovered energy was considered as renewable, and whether O+M: Multifamily is an applicable scheme. Also, Miljöbyggnad was challenging to use in comparisons as its scoring system cannot be directly translated to similar weightings as in other systems (Skarrie 2019; Granbom 2019). Therefore, all weighting-related results considering Miljöbyggnad contain more inaccuracies than results considering other certification systems. This was anyway estimated to be a functional way of approximating the impact of indicator and aspect ratings (figure 14) (Granbom 2019). Not all problematic situations could be solved by specialists either. More accurate assumptions could have been made by a person more specialized in such buildings and their systems. Ideally, when conducting this type of a study, an expert on green building certification schemes should be consulted often when doing the assessment.

The ever-increasing demand of apartment building renovations requires more research on the topic. Because of the low heating need of apartment buildings during summertime, working in cooperation with district heating companies could be a solution benefiting both housing companies and these energy companies. Investigating whether the energy companies were interested in purchasing heat pump energy produced in apartment buildings in order to shut down their production plants for the summer would be interesting. As the need and importance of prefabricated and modular solutions was shown throughout the thesis, modular heat pump solutions should be further studied, especially when the interest in using hybrid energy systems seems to be increasing and can be predicted to further increase.

Awareness about global environmental problems as well as the impact of different chemicals and materials on our own health has clearly been rising especially among young people, which will surely result to increasing demand for healthier and more environmentally-friendly buildings. This sustainability trend has no end in sight. Therefore, the demand of green building certifications has no end in sight, and this thesis has shown that building system renovations can play a great role when pursuing a certificate.

9 SUMMARY

Buildings account for approximately 40 % of both energy consumption and emissions in the EU. The EU has set stricter energy use requirements for new construction, and more focus needs to be put on existing buildings in order to decrease the massive negative impact of buildings. Aspects related to climate change, digitalization, urbanization and diminishing resources are gaining importance worldwide, and they result to different, increasing trends in the building industry, such as sustainable building practices, need of energy-saving renovations and using prefabricated and digital solutions. One method to reduce the environmental impact of buildings is to increase the use of green building certification systems, which measure the sustainability performance of a building and encourage making sustainable choices. Because the demand of renovations increases, the possibility to use green building certification systems during renovation was chosen to be investigated. The scope was chosen to include Finnish apartment buildings built during 1976-2002, because this is a quite large and relatively homogeneous building stock in terms of structural and technical solutions. According to previous studies, renovation measures on the building envelope are rarely cost-effective in these buildings, which is why only building system –related renovation measures were focused on in this thesis. These buildings generally use district heating and mechanical exhaust ventilation, and the common problems are related to the insufficient comfortable supply air flow and large heating losses in ventilation, due to the lack of mechanical supply ventilation and exhaust air heat recovery. The most feasible building system renovation options for these buildings according to studies included combinations of GSHP, EAHP, solar PV, solar thermal and wastewater heat recovery, while changing to energy-efficient windows and upgrading to mechanical supply ventilation with demand control were also important, but more envelope-related and less cost-effective measures.

Five most common green building certification systems were presented, and finding a suitable certification type i.e. scheme for apartment buildings undergoing building system renovations, which are rather minor, proved to be challenging. The schemes that could be considered for these types of renovation projects were American LEED O+M: EB/Multifamily, Nordic Ecolabel for repair construction and RTS GLT for residential buildings. Swedish Miljöbyggnad was also included because of its prevalent use for Swedish apartment buildings for years and its flexibility; being able to choose suitable assessment criteria based on whether the building part is renovated or not. The possible impact of a building system renovation in these schemes was investigated by going through the assessment criteria and finding the weighting of criteria related to technical systems. The share of building system –related criteria in LEED O+M: EB/Multifamily was 41 %, in RTS GLT 36 %, in Nordic Ecolabel 16 % and in Miljöbyggnad up to 58 %. However, the rating system of Miljöbyggnad is very different and any results related to the possible shares or points are rough estimates. Also, Nordic Ecolabel consists of only obligatory criteria and LEED has several obligatory requirements as well, reducing the accuracy of the results. To be able to get more intricate results, the impact of most feasible building system renovation options was estimated in these four schemes by estimating possible point improvements using typical values for the assessed building stock and renovation measures as a basis. The most points were clearly provided by installing a GSHP or an EAHP, providing already approximately 20 % of the total points in LEED and Miljöbyggnad, mostly because of their high energy-saving potential. RTS GLT and especially Nordic Ecolabel gave low points for the renovation measures all around. LEED O+M valued water-saving measures clearly more than the other systems.

The impacts were also estimated with the help of a case building well representative of the examined building stock. Because Nordic Ecolabel requires renovations consisting of least 25 % of the building value or envelope area, RTS GLT and LEED O+M: EB/Multifamily were chosen to be used for assessing the case building. Because the renovation in the case building was still in project planning phase, the renovation measures could only tentatively be defined to be installing EAHP with CO_2 refrigerant, PV panels and drainpipe heating cables as well as motion-controlled LED lighting and suitable BAS measures. These measures would halve the bought energy consumption and increase the approximate share of renewable energy consumption from over 45 % to over 80 %, when household electricity consumption is excluded. These impacts could be seen in green building certification assessments as well: before the renovation the building was estimated to receive 10 points in LEED O+M and after the renovation 34 points in LEED O+M and 12.5-14.5 points in RTS GLT, when approximately 110 points are available in both schemes. It is important to note that only building system-related criteria, slightly over a third of total criteria depending on the certification scheme, could be assessed. Because the assessments were mostly based on estimations and simplified calculations, the results contain inaccuracies.

Based on previous studies, there are many advantages to green apartment buildings and green building certifications, as well as to prefabricated solutions. However, they require more time, precision and resources in planning phases, and both of these approaches should be incorporated in the renovation planning from early on. The impacts of prefabrication in certification systems should be assessed by having multiple case studies where prefabricated solutions are included in order to have valid data. Same applies to any building system renovation, because reliable initial values reduce the inaccuracies in point estimations. However, these results show that the impact of a building system renovation can be significant. By incorporating envelope measures, especially such measures that improve comfortable supply air flow, the selection of applicable certification schemes would be broader. Furthermore, the impacts of prefabrication would be seen clearer and the received certification points would probably increase.

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Appendix 1: Comparison of criteria in the different certification systems (criteria for new construction). Modified after (FIGBC 2018a, 6; SGBC 2015b.) NB! This table is only a brief comparison, and some shown aspects are considered deeper in some certification criteria and some schemes than in others.

Criterion	**LEED**	**BREEAM**	**RTS**	**Miljöbyggnad**	**Nordic Ecolabel**
LOCATION AND CONNECTIONS					
Traffic	X	X			
Choice of site	X	X			
Landscaping	X	X	X		
LCC		X			
Maintainability			X		X
Moisture risk control			X	X	X
ENERGY AND ENVIRONMENT					
Energy-efficiency	X	X	X	X	X
Water use	X	X	X		X
Reliability	X	X	X		X
MATERIALS					
Carbon footprint calculation	X	X	X	X	
Material efficiency	X	X	X		X
Responsible purchases		X			X
Waste management	X	X	X		X
INDOOR ENVIRONMENT					
Indoor air quality	X	X	X	X	X
Natural lighting	X	X	X	X	X

Material emissions	X	X	X	X	X
Chemical risks			X		X
Acoustics	X	X	X	X	X
BUILDING SITE MANAGEMENT					
Environmental management	X	X	X		X
Clean building site	X		X		
Waste management	X		X		X

Appendix 2: Criteria of LEED O+M: EB/Multifamily, v 4 (USGBC 2018), points as in Multifamily. The only difference with points in EB and Multifamily is in criterion Interior lighting, which gives maximum 2 points in EB and 1 in Multifamily. The last column is left empty if the relation between the criterion and a building system renovation is clear or no further comments have to be added. NB! There are usually two different methods for receiving points for each credit and the methods sometimes give different amounts of points, here the maximum points are shown. The method of filling the criteria varies occasionally between EB and Multifamily.

CREDIT/PREREQUISITE	**MAXIMUM POINTS**	**Relation with building system renovation**
LOCATION & TRANSPORTATION (LT)		
Alternative transportation	15	Close to none – requires changes in travel possibilities
SUSTAINABLE SITES (SS)		
Site management policy	required	Can be done
Site development – Protect or restore habitat	2	Close to none, but could be done (e.g. donating money to charity)
Rainwater management	3	None, unless rainwater is used for e.g. flushing
Heat island reduction	2	Close to none, but shading by solar panels etc. affects the points
Light pollution reduction	1	Can be done – shielding of lamps
Site management	1	Operational improvements
Site improvement plan	1	
WATER EFFICIENCY (WE)		
Indoor water use reduction	required + 5	
Building-level water metering	required	
Outdoor water use reduction	2	

Cooling tower water use	3	Can affect, if number of condensation cycles is decreased in cooling tower
Water metering	2	
ENERGY AND ATMOSPHERE (EA)		
Energy efficient best management practices	required	Can be done – conducting an energy audit
Minimum energy performance	required	
Building-level energy metering	required	
Fundamental refrigerant management	required	
Existing building commissioning - Analysis	2	Small – mostly operational improvements and plans
Existing building commissioning – Implementation	2	
Ongoing commissioning	3	
Optimize energy performance	20	Yes – when increasing energy efficiency
Advanced energy metering	2	
Demand response	3	
Renewable energy and carbon offsets	5	
Enhanced refrigerant management	1	
MATERIALS AND RESOURCES (MR)		
Ongoing purchasing and waste policy	required	Can be done – mostly making policies and plans
Facility maintenance and renovation policy	required	
Purchasing – Ongoing	1	
Purchasing – Lamps	1	
Purchasing – Facility maintenance and renovation	2	Can be done – by using sustainable materials
Solid waste management – Ongoing	2	Can be done
Solid waste management – Facility maintenance	2	

and renovation		
INDOOR ENVIRONMENTAL QUALITY (EQ)		
Minimum indoor air quality performance	required	
Environmental tobacco smoke control	required	Can be done
Green cleaning policy	required	
Indoor air quality management program	2	
Enhanced indoor air quality strategies	2	Yes – by e.g. filters
Thermal comfort	1	
Interior lighting	1 (2 in EB)	
Daylight and quality views	4	
Green cleaning – Custodial effectiveness assessment	1	Could be done, but require more actions than making plans, therefore not colored with grey
Green cleaning – Products and materials	1	
Green cleaning – Equipment	1	
Integrated pest management	2	
Occupant comfort survey	1	Can be done – optimal building systems affect
INNOVATION (IN)		
Innovation	5	
LEED accredited professional	1	Can be included
REGIONAL PRIORITY		
Regional priority	4	
total	109	

Appendix 3: Criteria of RTS GLT – residential buildings (RTS 2019a). The criteria are colored according to the measure groups a-c (as explained in chapter 6.1) which most probably affect them: the criteria affected by the a-group are highlighted with yellow and the groups b-c with grey. The last column is left empty if the relation between the criterion and a building system renovation is clear or no further comments have to be added.

CATEGORY	CRITERIA	MAX. POINTS	Relation with building system renovation
PROCESS	**Project management**		
	P1.1 Steering and management of the classification target	3	Mostly management-related measures, that can or should be done during renovation
	P1.2 Ensuring and monitoring the functionality of building services	3	
	P1.3 User guidance	2	
	Moisture control		
	P2.1 Managing risks related to moisture technology as part of the design	4	
	P2.2 Managing moisture on the construction site	6	
	Construction site management		
	P3.1 Environmental impact of the construction site	3	
	P3.2 Cleanliness management on the construction site	2	
FINANCES	T1.1 Life cycle costs	3	Small, only 25 % of points given when the most cost-efficient option is chosen; 75 % for making the calculations
	Maintainability		
	T2.1 Durability	3	None – mostly structure-related

	T2.2 Maintenance	4	
	T2.3 Adaptability	2	Close to none – creating an adaptable space
ENVIRONMENT AND ENERGY	**Carbon footprint**		
	Y1.1 Life cycle carbon footprint	7	75 % of points from decreasing the footprint
	Y1.2 Material efficiency	4	
	Energy		
	Y2.1 Energy efficiency	8	
	Y2.2 Measuring energy use	3	
	Y2.3 Calculating the target consumption	3	
	Y2.4 Efficiency of systems	2	
	Water		
	Y3.1 Efficiency of water use	3	Yes - measuring and installing water-saving fixtures
	Impacts on the environment		
	Y4.1 Constructing green spaces and managing storm water	3	Close to none – mostly structure-related
	Y4.2 Safety and priority of cycling and walking	2	Could be done, however requires some construction outside of the building
INDOOR AIR AND HEALTH	**Indoor air quality**		
	S1.1 Thermal conditions	6	
	S1.2 Indoor air quality	7	
	S1.3 Opportunities for occupants to make adjustments	2	

	S1.4 Material emissions	3	Could be done – mostly measurements and using low-emission materials
	Visual comfort		
	S2.1 Amount of natural light	4	
	S2.2 Quality of lighting	2	
	Acoustics		
	S3.1 Indoor acoustics	3	
	S3.2 Noise insulation	3	
	I Innovation	10	
	total	110	

Appendix 4: Criteria of Nordic Ecolabel (repair construction). All required to be filled, no points are given. (Ecolabelling Finland 2017.) The last column is left empty if the relation between the criterion and a building system renovation is clear or no further comments have to be added.

Criterion		Relation with building system renovation
General requirements		Can always be done during renovation, mostly plans
O1	Outline description of the renovation project	
O2	Responsibility for Nordic Swan Ecolabelling	
Prior to renovation work		
O3	Building condition assessment and plan for resource use	
O4	Environmental analysis/survey and remediation plan	
O5	Moisture survey	
Resource effective material management		
O6	Waste plan and waste management	
O7	Follow-up of remediation plan	
Indoor environment		
O8	Indoor air quality	Can affect, when renovating ventilation systems
O9	Radon	Can be affected when ventilation is optimized
O10	Moisture prevention	None – construction-related
O11	Ventilation	
O12	Measurement of PCB (polychlorinated biphenyl) levels in indoor air	Can affect, if construction materials included PCB and were removed – but more structure-related
O13	Noise environment (only in pre-schools and schools)	

Energy use and climate change	
O14 The energy demand of the building after renovation	
O15 Lighting	
O16 Energy-efficient white goods	Can affect, when upgrading white goods
Sustainable products and materials	Can affect, when made sure, that these are not used in renovation – however mostly structure-related (criteria apply only to new materials)
O17 Product list and logbook of the building	
O18 Classification of chemical products	
O19 CMR substances (carcinogenic, mutagenic, reprotoxic)	
O20 Preservatives in indoor paints and varnishes	
O21 Preservatives in other chemical products for indoor use	
O22 Other substances excluded from use	
O23 Nanoparticles in chemical products	
O24 Excluded substances in construction products, construction goods and materials	
O25 Nanoparticles and antibacterial additives in construction products and construction goods	
O26 Formaldehyde emissions	
O27 Construction products made of polyvinyl chloride (PVC)	
O28 Epoxy relining	
O29 Copper in domestic water pipes and as façade and roofing material	
O30 Requirements for reused construction products	
O31 Resource-efficient material selection	
O32 Tree species that may not be used in Nordic Swan Ecolabelled renovations	
O33 Wood raw materials	
O34 Durable/resistant wood for outdoor use	
Other sustainability initiatives	

O35 Sustainability initiatives	
Information for property managers and residents/users	Can be done during renovation - mostly management and documentation-related
O36 Maintenance/service/operation documentation	
Quality management of the renovation process	
O37 Management of requirements for products and materials	
O38 Information to those involved in the renovation process	
O39 The contractor’s self-monitoring	
O40 Inspection of the renovated building	
Quality and regulatory requirements	
O41 Documentation	
O42 Documentation of the renovated buildings	
O43 Planned changes	
O44 Unforeseen non-conformities	
O45 Complaints	
O46 Laws and regulations	

Appendix 5: Complete criteria of Miljöbyggnad new construction, and the criteria for existing buildings and typical criteria for renovation compared to new construction (SGBC 2015b; SGBC 2019b.). The mark -“- is used to indicate the criteria that are the same as in criteria for new construction. The last column is left empty if the relation between the criterion and a building system renovation is clear or no further comments have to be added.

		New construction	Existing buildings	Renovation	Relation with building system renovation
ENERGY	1	Heat demand	-“-	-“-	
	2	Solar gain	-“-	-“-	None – share of window area affects, but in existing buildings installing blinds can affect
	3	Energy consumption	-“-	-“-	
	4	Share of renewable energy	-“-	-“-	
INDOOR ENVIRONMENT	5	Noise	-“-	-“-	Small – sound from building systems can affect
	6	Radon	-“-	-“-	Can be affected when ventilation is optimized
	7	Ventilation	-“-	-“-	
	8	Moisture safety	-“-	-“-	None – only construction- and water damage-related
	9	Thermal climate, winter	-“-	-“-	Can affect (e.g. cooling), measured mostly by a maximum PPD (predicted percentage of dissatisfied)
	10	Thermal climate, summer	-“-	-“-	
	11	Daylight	-“-	-“-	

	12	Legionella	-“-	-“-	Can affect, when e.g. measuring water temperatures
MATERIALS	13	Logbook of building materials		-“-	Can be created
	14	Phasing out hazardous substances		-“-	Can affect, if these substances are removed
	15	Climate impact of the building frame			
	16		Removing hazardous substances	Removing hazardous substances	Can affect, when having low-GWP refrigerants

Appendix 6: Estimations of possible impacts of renovation measures (as described in chapter 6.2) in LEED O+M points (USGBC 2018). The impacts are estimated as both points and shares of the criterion. Only the criteria most affected by building renovation measures are shown.

LEED O+M: EB/MULTIFAMILY		**Renovation measures**						
Criterion	**Weighting of credit (as in EB)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Indoor water use reduction	4.5 % (also required)	-	-	fulfilled + 3 (60 %)	-	-	-	-
Building-level water metering	required	-	-	fulfilled	-	-	-	-
Cooling tower water use	2.7 %	-	-	-	-	-	-	-
Water metering	1.8 %	-	-	2 (100 %)	-	-	-	-
Minimum energy performance	required	Significant impact	Significant impact	Small impact	Small impact	Medium impact	Medium impact	Small impact
Building-level energy metering	required	-	-	-	-	-	-	-
Fundamental refrigerant management	required	-	-	-	-	-	-	-
Optimize energy performance	18.2 %	14 (70 %)	20 (100%)	-	-	-	-	-

Advanced energy metering	1.8 %	-	-	-	-	-	-	-
Demand response	2.7 %	No impact, unless demand response applications installed	-“-	-“-	-“-	-“-	-“-	-“-
Renewable energy and carbon offsets (difficult to estimate, because original share cannot be assumed)	4.5 %	Significant impact, assumed to give 4 points (80 %)	Significant impact, assumed to give 5 points (100 %)	Does not necessarily impact	Does not necessarily impact	Medium impact, assumed to give 2 points (40 %)	Medium impact, assumed to give 2 points (40 %)	Medium impact, assumed to give 2 points (40 %)
Enhanced refrigerant management	0.9 %	-	-	-	-	-	-	-
Minimum indoor air quality performance	required	-	-	-	-	-	-	-
Enhanced indoor air quality strategies	1.8 %	-	-	-	-	-	-	-
Thermal comfort	0.9 %	-	-	-	-	-	-	-
Interior lighting	0.9 %	-	-	-	1 (100 %)	-	-	-
Total points (weighting)	**41 %**	**18 (16.3 %)**	**25 (22.7 %)**	**5 (4.5 %)**	**1 (0.9 %)**	**2 (1.8 %)**	**2 (1.8 %)**	**2 (1.8 %)**

Appendix 7: Estimations of possible impacts of renovation measures (as described in chapter 6.2) in RTS GLT points (RTS 2019a). The impacts are estimated as both points and shares of the criterion. Only the criteria most affected by building renovation measures are shown.

RTS GLT		**Renovation measures and the estimated points**						
Criterion	**Weighting of credit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Y1.1 Life cycle carbon footprint	6.4 %	4.2 (60 %)	5.3 (75 %)	-	-	1 (15 %)	1 (15 %)	-
Y2.1 Energy efficiency	7.3 %	1.6 (20 %)	2.4 (30 %)	-	-	-	-	-
Y2.2 Measuring energy use	2.7 %	-	-	-	-	-	-	-
Y2.4 Efficiency of systems	1.8 %	-	-	-	Approx. 1 point (50 %)	-	-	-
Y3.1 Efficiency of water use	2.7 %	-	-	1.5 (50 %) (bathroom fixtures with low water use required also)	-	-	-	-
S1.1 Thermal conditions	5.5 %	-	-	-	-	-	-	-
S1.2 Indoor air quality	6.4 %	-	-	-	-	-	-	-
S1.3 Opportunities for occupants to make	1.8 %	-	-	-	-	-	-	-

adjustments								
S2.2 Quality of lighting	1.8 %	-	-	-	1.3 (66 %) (requires lighting quality in households as well)			
Total points (weighting)	**36 %**	**5.8 (5.3 %)**	**7.7 (7 %)**	**1.5 (1.4 %)**	**2.3 (2.1 %)**	**1.0 (0.9 %)**	**1.0 (0.9 %)**	**0**

Appendix 8: Estimations of possible impacts of renovation measures (as described in chapter 6.2) in Nordic Ecolabel points (Ecolabelling Finland 2017). The impacts are estimated as shares of the criterion. Only the criteria most affected by building renovation measures are shown.

NORDIC ECOLABEL		**Renovation measures**						
Criterion	**Weighting of credit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
O8 Indoor air quality	2.2 %	-	-	-	-	-	-	-
O9 Radon	2.2 %	-	-	-	-	-	-	-
O11 Ventilation	2.2 %	-	-	-	-	-	-	-
O14 The energy demand of the building after renovation	2.2 %	33 %	50 %	7 %	3 %	13 %	15 %	14 %
O15 Lighting	2,2 %	-	-	-	100 %	-	-	-
O16 Energy-efficient white goods	2.2 %	-	-	-	-	-	-	-
O35 Sustainability initiatives	2.2 %	100 %	100 %	Minimal, possibly 10 %	Small, possibly 20 %	100 %	100 %	100 %
Total weighting	**16 %**	**2.9 %**	**3.3 %**	**0.4 %**	**2.8 %**	**2.5 %**	**2.5 %**	**2.5 %**

Appendix 9: Estimations of possible impacts of renovation measures (as described in chapter 6.2) in Miljöbyggnad points (SGBC 2015b; SGBC 2019b). The impacts are estimated as shares of the criterion. Only the criteria most affected by building renovation measures are shown. NB! The weightings are rough approximations, and the rating is determined by rules introduced in chapter 4.3.

MILJÖBYGGNAD		**Renovation measures**						
Criterion	**Weighting of credit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Heat demand (ventilation heat losses have an impact, therefore heat recovery has some impact)	5.5 %	When no ventilation heat loss assumed, impact 37 % (figure 5)	-	-	-	Wastewater HR not included	-	-
Energy consumption (similar to E-value, without household electricity)	11 %	66 %	93 %	10 %	3 %	16 %	22 %	16 %
Share of renewable energy (difficult to estimate, because original share cannot be assumed)	11 %	Helps significantly (assumed to impact by 80 %)	Helps significantly (assumed to impact by 100 %)	Does not necessarily increase the share	Does not necessarily increase the share	Increases share slightly, impact on criterion assumed to impact by 20 %	Increases share slightly, impact on criterion assumed to impact by 20 %	Increases share slightly, impact on criterion assumed to impact by 20 %
Noise	5.5 %	-	-	-	-	-	-	-
Radon	2.75 %	-	-	-	-	-	-	-

Ventilation	2.75 %	-	-	-	-	-	-	-
Thermal climate, winter	2.75 %	-	-	-	-	-	-	-
Thermal climate, summer	2.75 %	-	-	-	-	-	-	-
Legionella	5.5 %	Can help if new accumulation tanks installed	-“-	-	-	Can reduce points if incorrectly designed	-	-
Removing hazardous substances	11 %	No impact, if use of high-GWP refrigerants not reduced	-“-	-“-	-“-	-“-	-“-	-“-
Total weighting	**61 %**	**18.1 %**	**21.2 %**	**1.1 %**	**0.3 %**	**4.0 %**	**4.6 %**	**4.0 %**

Appendix 10. Calculations for chapters 6.2 and 7.

CHAPTER 6.2

Assumptions:

- PV electricity can be used entirely in the buildings (probably requires a battery)
- When building data was needed, building volume was assumed to be 13 000 m^3, net heated area 4000 m^2 and number of apartments 51 (approximate data from case building)
- Because of the presumed low energy production of wastewater heat pump, its electricity consumption was ignored
- Other assumptions in table 8
- NB! Commas used as decimal separators in tables

Initial average & approximate values for calculations (for estimating electricity use increase)

Before the renovation (sources: chapter 2.4 and above-mentioned assumptions)		
district heat consumption (kWh)		650 000
household electricity consumption (kWh)		130 000
electricity use in common spaces (kWh)		54 600
energy consumption, with households (kWh)		834 600
energy consumption, without households (kWh)		704 600
approx. share of household electricity	in total electricity use	70,4 %
	in total energy use	15,6 %

After the renovation	**installing EAHP**, COP assumed to be 4:	**installing GSHP**, COP assumed to be 4.5:
district heat consumption (kWh)	195 000	65 000
heat pump heat production (kWh)	455 000	585 000
heat pump electricity use (kWh)	113 750	130 000
electricity consumption, with households (kWh)	298 350	314 600
electricity consumption, without households (kWh)	168 350	184 600
electricity consumption change, with households	62 %	70 %
electricity consumption change, without households	208 %	238 %
energy consumption change, with households	-41 %	-55 %
energy consumption change, without households	-48 %	-65 %

Point estimations

LEED O+M

EA Minimum energy performance, EA Optimize energy performance

household electricity excluded, makes results more inaccurate

Average energy consumption according to chapter 2.4 (kWh/m^3)	54,2	
consumption after renovation measure		improvement (%)
1 (kWh/m^3)	32,5	-40 %
2 (kWh/m^3)	21,7	-60 %
3 (kWh/m^3)	51,2	-6 %
4 (kWh/m^3)	53,7	-1 %
5 (kWh/m^3)	48,7	-10 %
6 (kWh/m^3)	48,0	-12 %
7 (kWh/m^3)	51,7	-5 %

EA Renewable energy and carbon offsets

assumed that any recovered heat considered as renewable energy (the criterion defines the applicable energy sources only as renewable)

RTS GLT

Y1.1 Life cycle carbon footprint

approx. share of the life cycle carbon footprint of a building composed by use phase (Bionova 2017)	70 %
(RTS calculation excludes household electricity)	
Carbon footprint savings, according energy savings in LEED calculation (above)	
measure 1	-28 %
measure 2	-42 %
measure 3	-4 %
measure 4	-1 %
measure 5	-7 %
measure 6	-8 %
measure 7	-3 %

Y2.1 Energy efficiency

building gross volume assumed to be 13000 m^3 and heated area 4000 m^2
average consumption values assumed to be equal to those in chapter 2.4.,
e.g. 51 households - 130 MWh household electricity consumption

only bought energy taken into account, E-value according to equation 1: (kWh/m^2)	137
E-value after renovation measure:	
1 (kWh/m^2)	114
2 (kWh/m^2)	102
3 (kWh/m^2)	132
4 (kWh/m^2)	135
5 (kWh/m^2)	128
6 (kWh/m^2)	126
7 (kWh/m^2)	127

NORDIC ECOLABEL

O14 The energy demand of the building after renovation
To fulfill the criterion, energy consumption has to be 80 % or less of the D 4/13 requirement (130 kWh/m^2): 104

calculation as above, RTS GLT criterion Y2.1 Energy efficiency

E-value (kWh/m^2)	136,63		
E-value after renovation measure			
1 (kWh/m^2)	113,8	-16,7 %	-33 %
2 (kWh/m^2)	102,5	-25,0 %	-50 %
3 (kWh/m^2)	131,8	-3,6 %	-7 %
4 (kWh/m^2)	134,7	-1,4 %	-3 %
5 (kWh/m^2)	127,7	-6,5 %	-13 %
6 (kWh/m^2)	126,5	-7,4 %	-15 %
7 (kWh/m^2)	126,8	-7,2 %	-14 %

impact on criterion assumed to be double the above (last column), because of the small differences between energy classes

Miljöbyggnad
Energy consumption, according to (BBR 2018, 135-146)

geographical factor assumed to be 1,2 (Southern Finland); building gross volume assumed to be 13000 m^3 and heated area 4000 m^2)
average consumption values assumed to be equal to those in chapter 2.4

consumption (kWh/m^2)	164,0		
approximate consumption after renovation measure, according to table 8		change (%)	
1 (kWh/m^2)	109,9	-33 %	-66 %
2 (kWh/m^2)	88,0	-46 %	-93 %
3 (kWh/m^2)	155,5	-5 %	-10 %
4 (kWh/m^2)	161,4	-2 %	-3 %
5 (kWh/m^2)	150,6	-8 %	-16 %
6 (kWh/m^2)	146,3	-11 %	-22 %
7 (kWh/m^2)	150,9	-8 %	-16 %

impact on criterion assumed to be double the above, because of the small differences between energy classes (Boverket 2018, 3)

CASE BUILDING, CHAPTER 7

Calculations for figure 21, annual values

electricity consumption in common spaces (2016) (kWh)	57 900		
district heating consumption (normalized) (2016) (kWh)	568 300		
water consumption (2016) (m^3)	3 697		
household electricity consumption (kWh)	130 050		
gross volume (m^3)	12 988		
primary energy consumption (without household electricity) kWh	626 200		
Impacts of EAHP (COP 4.3)			
reduction in district heating: (kWh)	170 490		
EAHP heat production (kWh)	397 810		
EAHP electricity use (kWh)	92 514		
electricity use increase (%)	160 %		
total primary energy reduction (%)	58 %		
Impacts of solar panels (20 kW_p)		(southern Finland)	
electricity production (kWh)	14 000	**20 000**	
electricity use decrease without EAHP (%)	24 %	**35 %**	
electricity use decrease with EAHP (%)	9 %	**13 %**	
Impacts of motion-controlled LED lighting			
total electricity use reduction (kWh)	3474		
Final estimated values after renovation		kWh/m^3	change (%)
district heat consumption (kWh)	170 490	13,1	-70 %
electricity consumption (kWh)	126 940	9,8	119 %
water consumption (m^3)	3 697		0 %
primary energy consumption (kWh) (households not taken into account)	297 430	22,9	-53 %

Calculations for certification point estimations in chapter 7.3 according to (USGBC 2018; RTS 2019a)

EXISTING BUILDING (LEED O+M)	
EA Minimum energy performance (Virta & Pylsy 2011, 21-23)	
avg. energy consumption in apartment buildings built in 1993 (kWh/m^3)	51,2
avg. energy consumption in case building in 2016 (kWh/m^3)	48,3
difference	-6 %
EA Renewable energy and carbon offsets	
heat produced by renewables (kWh/a)	261 418
electricity produced by renewables (kWh/a)	38 600
purchased renewable energy share (%)	48 %
points:	1,92

RENOVATED BUILDING (LEED O+M)	
EA Minimum energy performance (Virta & Pylsy 2011, 21-23)	
avg. energy consumption in apartment buildings built in 1993 (kWh/m^3)	51,2
avg. energy consumption in case building in 2016 (kWh/m^3)	22,9
difference	-55 %
EA Renewable energy and carbon offsets	
total energy demand not expected to change (kWh/a):	626 200
heat produced by renewables (kWh/a)	78 425,4
heat produced by renewables on-site (kWh/a)	397 810
electricity produced by renewables (kWh/a)	84 626,6
electricity produced by renewables on-site (kWh/a)	20 000
purchased renewable energy share of all energy (%)	26 %
generated renewable energy share of all energy (%)	67 %
points:	45,52

RENOVATED BUILDING (RTS GLT)

Y1.1 Life cycle carbon footprint

Typical share of use phase in building's life cycle (Bionova 2017)	70 %
Carbon footprint reduction with 53 % energy use reduction	-37 %

average CO_2 factors can be used both for the case building and the reference building
+ low-carbon electricity reduces carbon footprint even more
(households are not and should not be included in the calculations)
(unchanged values assumed to be the same as in reference building)

Y2.1 Energy efficiency

Before renovation

assumed that net heated area is 85 % of total building area (m^2):	3 775,7
household electricity consumption assumed as in previous calculations (kWh)	130 050
according to eq. 1, (kWh/m^2)	135,0

After the renovation

household electricity consumption not expected to change

only bought energy taken into account in eq. 1

according to eq. 1 (kWh/m^2)	104,2
because of inaccuracies actual E-value probably between (kWh/m^2)	99-110