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Methods and concepts for sustainable renovation of buildings

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Sakari Pulakka | Ilpo Kouhia | Riikka Holopainen

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Methods and concepts for sustainable renovation of buildings

[Kestävän korjausrakentamisen menetelmät]. **Tarja Häkkinen, Antti Ruuska, Sirje Vares, Sakari Pulakka, Ilpo Kouhia, Riikka Holopainen.** Espoo 2012. VTT Technology 26. 266 p. + app. 51 p.

Abstract

This report presents the main results of the research project Methods and Concepts for sustainable Renovation (MECOREN) carried out at VTT in 2009–2012.

The overall research project was a Nordic collaboration between the following research partners: VTT in Finland, SINTEF in Norway, SBI in Denmark and KTH in Sweden.

This report presents methods and concepts for building renovation and analyses the impacts of alternative renovation scenarios on Finnish building stock in terms of energy use and carbon footprint. The focus of the study is on residential buildings. The calculations were carried out for years 2010, 2020 and 2030.

In addition to the assessment of the renovation concepts of building stock, the report also

- discusses and gives recommendations about the use of environmental data for energy sources
- discusses and makes conclusions about the significance of building materials in renovation projects from the view point of greenhouse gases and total energy use
- discusses and make recommendations about different renovations concepts
- assesses and makes conclusions about the economic impacts of building renovation.

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Keywords sustainable, renovation, assessment methods, renovation concept

Kestävän korjausrakentamisen menetelmät

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Tiivistelmä

MECOREN oli pohjoismainen tutkimushanke, jonka tavoitteena oli kehittää konsepteja kestävään korjausrakentamiseen, kehittää menettelytapoja ja ohjeita kestävän korjausrakentamisen arviointiin sekä arvioida rakennuskannan ja rakennusten korjausvaihtoehtojen elinkaarivaikutuksia.

Hanke alkoi helmikuussa 2009 ja se päättyi huhtikuussa 2012. VTT koordinoi hanketta; muut tutkimuskumppanit olivat KTH Ruotsista, SINTEF Norjasta ja SBI Tanskasta.

Kansallisen hankkeen päärahoittaja oli TEKESin kestävän korjausrakentamisen tutkimusohjelma. Hankkeen muita rahoittajia olivat VTT, Senaatti-kiinteistöt, Helsingin kaupunki, Tampereen kaupunki ja Ilmarinen.

Hankkeen tulokset on koottu tähän raporttiin ja hankkeen tulokset ja hankkeen loppuseminaarissa pidetyt esitelmät ovat saatavilla myös MECORENin internet-sivulla osoitteessa http://www.vtt.fi/sites/mecoren/?lang=en

Euroopan Unionin kestävän kasvun tavoitteeseen sisältyvät kasvihuonekaasujen vähentäminen 20 %:lla vuoteen 2020 mennessä ja edelleen 20 %:lla vuosikymmenessä siten, että vuoteen 2050 vähennys on peräti 80 % verrattuna vuoden 1990 tasoon. On todettu, että rakennetun ympäristön energiatehokkuuden merkittävä parantaminen ja uusiutuvien energialähteiden hyödyntäminen rakennetun ympäristön käytössä on yksi kustannustehokkaimmista tavoista tavoitteeseen pääsemiseksi.

MECOREN-hankkeen tulokset vahvistavat ymmärrystä siitä, että jopa vanhat rakennukset voidaan korjata energiatehokkuudeltaan passiivitasoon. Hyvän, perusteellisen korjauksen keskeisiä tekijöitä ovat huolellinen suunnittelu ja rakentaminen, erittäin hyvä lisäeristys ja ilmatiiviyden parantaminen, mekaaninen ilmastointi ja tehokas lämmön talteenotto, energiatehokkaat ikkunat ja sähkö- tai öljylämmityksen muuttaminen kaukolämmitykseen tai uusiutuvien energialähteiden hyödyntämiseen. Energiatehokkuuden merkittävä parantaminen aiheuttaa perusteellisen korjauksen yhteydessä 10–50 %:n lisän investointikustannuksissa. Arviot osoittavat, että takaisinmaksuaika on kuitenkin kohtuullisen lyhyt, kun otetaan huomioon käyttökustannusten pieneneminen ja arvon nousu. Mahdollisuutta kustannustehokkaaseen hyvään energiakorjaukseen ei saisi hukata minkään peruskorjauksen yhteydessä, vaikka määräykset eivät siihen vielä tällä hetkellä velvoita, koska perusteellisen korjauksen tarve yksittäisen rakennuksen kohdalla toistuu harvoin.

Hankkeessa tehdyt arviot korjausvaihtoehtojen merkityksellisyydestä kansantalouden tasolla rinnastettiin Suomen kasvihuonekaasujen kokonaispäästöihin ja loppuenergian kokonaiskulutukseen. Kasvihuonekaasujen kokonaispäätöt Suomessa olivat 66 Mt vuonna 2009. Vuonna 2010 Suomen loppuenergian kokonaiskulutus oli 279 TWh. Rakennusten osuus tästä oli 70 TWh + 24 TWh (koti- ja maataloussähkö). Vaikka rakennetun ympäristön korjaamisen on todettu olevan kustannustehokkain keino saavuttaa säästöjä, niin

on kuitenkin huomattava, että rakennusten energiatehokkuutta on parannettava huomattavasti, jotta vähennyksellä on merkittävää maatasoista vaikutusta. Esimerkiksi koko asuinrakennuskannan lämmöntarpeen täytyisi pienentyä 30 %:lla jotta loppuenergiankäyttö Suomen tasolla vähenisi 5 %:lla. Vastaavasti 10 %:n lasku vaatisi, että koko asuinrakennuskannan energiankulutus vähenisi 60 %:lla.

Koko Suomen asuinrakennuskannan pinta-ala on noin 270 Mm2. Tästä merkittävän osan – noin kaksi kolmasosaa – muodostavat 1940–2000 -lukujen omakotitalot ja 1960- ja 1970-lukujen kerrostalot. Asuinrakennusten kohdalla merkittävimmät energiatehokkuuden ja hiilijalanjäljen parannukset saadaan aikaan vaipan lisäeristyksellä passiivitasoon sekä lämmitystavan muutoksin. Kun ilmatiiviyttä parannetaan, niin samassa yhteydessä on tarpeen tehdä myös ilmanvaihdon korjaus ja lämpimän ilman talteenotto. Kun asuinrakennuskannan suhteen otettiin huomioon poistuma ja eri-ikäisten rakennusten korjaustarve ja oletettiin, että merkittävä energiakorjaus tehdään vain merkittävien yleisten korjaustarpeiden yhteydessä, niin tulokseksi saatiin, että vuoteen 2030 mennessä

- poistuma merkitsee 7 TWh.n vähennystä loppuenergiankulutuksessa ja 1,7 Mt:n vähennystä kasvihuonekaasujen päästöissä
- enimmäissäästöt energiakorjausten kautta merkitsevät 15 kWh:n säästöä loppuenergian kulutuksessa ja 3,1 Mt:n säästöä kasvihuonekaasujen päästöissä
- öljy- ja sähkölämmitteisten yksittäistalojen lämmitysmenetelmän muutokset merkitsevät 7 TWh:n säästöä loppuenergiankukutuksessa ja 4,3 Mt:n säästöä kasvihuonekaasujen päästöistä.

Toimitalojen energiatehokkuuden parantaminen on tilojen ja teknologian rajaama ja mahdollistama toimintatapa. Hankesuunnittelussa asetetaan kiinteistöarviointiin ja toimivuusvaatimuksiin kytketyt energiatehokkuustavoitteet. Yleis- ja toteutussuunnittelun keinoin määritetään omistaja-käyttäjä-suunnitteluyhteistyössä ko. tavoitteet täyttävät arkkitehtoniset (esteettisyys, tilasuunnittelu), talotekniset ja rakennetekniset toteutusratkaisut. Tällöin uusitaan usein valtaosa talotekniikasta siten, että eri kulutuskohteiden laitteiden tulee olla hyötysuhteeltaan mahdollisimman hyviä ja varustettu tarkoituksenmukaisella vyöhykekohtaisella ohjauksella ja säädöillä. Samoin parannetaan vaipan eristystasoa ja tiiveyttä, millä vanhentuneiden rakennusten kohdalla iso merkitys. Uusiutuvan energian hyödyntäminen toteutetaan yleensä enemmänkin alue- kuin rakennustasolla.

Kun arvioidaan korjausvaihtoehtojen energiansäästöpotentiaalia ja siihen liittyvä potentiaalia hiilijalanjäljen parantamisessa, on tärkeää, että johtopäätöksiä ei tehdä sähkön ja kaukolämmön keskimääräisten ominaispäästöjen pohjalta, vaan otetaan huomioon marginaalipäästöt ja vuodenaikakohtaiset vaihtelut.

Suomessa sähkön kysyntä on tällä hetkellä suurempi kuin tuotanto. Tarjontaa kasvatetaan tuomalla lähinnä Venäjältä fossiilisiin polttoaineisiin pohjautuvaa sähköä. Vaikka yhteistuotannon osuus Suomessa on eurooppalaisittain suuri, niin osa sähkön ja lämmön tuotannosta tapahtuu erillisissä fossiilisiin polttoaineisiin perustuvissa laitoksissa. Kysynnän vähenemiseen tiettyyn rajaan asti, voidaan periaatteessa vastata vähentämällä fossiilisiin polttoaineisiin perustuvaa tuotantoa.

Jos ominaispäästöjen vuosikeskiarvojen sijasta käytetään kuukausikeskiarvoja tai marginaaliarvoja, niin tällä on huomattava merkitys kasvihuonekaasujen päästöjen arvioinnissa. Kun Suomessa sähkön keskimääräinen ominaispäästö (laskemalla hyödynjakomenetelmällä ja tuonti huomioon ottaen) on noin 300 g/kWh, niin marginaaliarvo laskien hiililauhdevoimaan pohjautuvaan tuotantoon on sähkölle noin 1000 g/kWh. Tämä merkitsee myös sitä, että kun päämääränä on erityisesti kasvihuonekaasujen vähentäminen, niin energiakorjausten menetelmä tulisi valita niin, että se ei aiheuta huipputehon tarpeen kasvua.

Kaikissa kestävän rakentamisen potentiaalien arvioinneissa huomiota pitäisi kiinnittää entistä enemmän nimenomaisesti kasvihuonekaasujen säästöpotentiaaliin. Samalla olisi otettava kokonaisvaltaisesti huomioon korjauksen merkitys rakennuksen toimivuuden kannalta, elinkaarikustannusten ja taloudellisen arvon kannalta.

Arvioitaessa rakennusten elinkaarivaikutuksia ja eri osatekijöiden merkityksellisyyttä, olisi entistä enemmän otettava huomioon myös tulevaisuuden muutokset energiantuotannossa. Tämä yhdessä rakennusten paremman energiatehokkuuden kanssa voi vaikuttaa huomattavasti siihen, että tilojen lämmityksen ja kotitaloussähkön merkitys rakennusten koko elinkaaren aikaisesta hiilijalanjäljestä pienenee huomattavasti, kun taas lämpimän käyttöveden ja rakennusmateriaalien suhteellinen merkitys kasvaa huomattavasti.

Uusimpien arvioiden mukaan lämmön ja sähkön ominaispäästöt Suomessa tulevat kehittymään siten, että kun ominaispäästöt nyt ovat (energiamenetelmällä arvioituna) 230 ja 243 sähkölle ja kaukolämmölle, niin arvioidut päästöt vuonna 2030 ovat sähkölle ja kaukolämmölle 36 ja 191 g/kWh.

MECOREN-hankkeen tuloksissa annetaan ohjeita ja suosituksia erilaisista korjausmenetelmistä liittyen ulkopuoliseen lisäeristykseen, sisäpuoliseen lisäeristykseen, eristemateriaalin vaihtamiseen, kattojen lisäeristykseen, alapohja lisäeristykseen, ikkunoiden vaihtamiseen, vaipan ilmatiiviyden parantamiseen, ilmanvaihdon korjaamiseen ja lämmitysjärjestelmän vaihtamiseen.

Seinien ulkopuolinen lisäeristys on teoriassa hyvin turvallinen menettelytapa ja parantaa seinän rakennusfysikaalista toimintaa. Hankkeen yhteydessä kuitenkin osoitettiin, että jos seinärakenteeseen kuitenkin pääsee vuodon seurauksena ylimääräistä kosteutta, niin on olemassa kosteustekninen riski silloin, kun lisäeristyksessä käytetään tiivistä materiaalia. Näitä laskentatuloksia ei kuitenkaan julkaista MECORENin loppuraportin yhteydessä, vaan tulokset siirrettiin raportoitavaksi KORVI-hankkeen yhteydessä kesällä 2012 raportoitaviin laajempiin rakennusfysikaalisiin arvioihin korjausmenetelmien rakennusfysikaalisista riskeistä.

MECOREN -hankkeessa tehtiin myös toimijakohtaisia arvioita yksittäisten rakennusten korjaamisen energiasäästöpotentiaaleista. Tapaustutkimuksissa tarkasteltiin koulu-, lastentarha-, toimisto- ja asuinrakennuksia. Peruskorjauksen yhteydessä on hyvät mahdollisuudet säästää lämmitysenergiaa rakenteiden lisäeristämisellä ja tiivistämisellä sekä lisäämällä ilmanvaihtoon lämmön talteenotto. Sähkönkulutusta voidaan selkeästi pienentää energiatehokkaalla valaistuksella ja ilmanvaihdon tarpeenmukaisella ohjauksella (säästää sekä lämmitysenergiaa että sähköä).

Kestävän korjausrakentamisen vaikuttavuus koskee merkittäviä osa-alueita. Sen avulla voidaan päästä huomattavaan lämpöenergiankulutuksen alenemiseen ja hiilijalanjäljen pienenemiseen, huomattavasti parempaan elinkaaritaloudellisuuteen ja hyvään toimivuuteen. Toisaalta on otettava huomioon riskit, joita ovat energiantuotannon muutosten hallittavuus, konsultointipalvelujen ja korjauskonseptien riittävä kehittyminen ja korjattujen rakenteiden ja järjestelmien tekninen toimivuus. Kansantalouden tasolla mahdollisuudet koskevat paitsi kestävän kehityksen vaatimaa kasvihuonekaasujen vähenemistä myös

työllisyyden parantamista ja siihen kytkeytyvän koulutuksen kasvattamista sekä alueellisen rakentamisen ja energiantuotannon kokonaishallinnan kehittymistä.

MECOREN-hanke arvioi eritasoisesti tapahtuvan rakennusten energiakorjauksen vaikutusta ylimääräisiin investointikustannuksiin, tarvittavaan julkiseen tukeen ja työllisyyteen. Tarkasteltavia tasoja olivat määräysten mukainen taso, korjaus passiivitasoon ja korjaus lähes nollaenergiatasoon. Arvion mukaan esimerkiksi passiivitasoon korjattaessa (75 % kannasta joka tarvitsee perusteellista korjausta) ylimääräinen investointikustannus vuoteen 2030 mennessä on 1350 miljoonaa euroa vuodessa, tarvittava tuki 150–200 miljoonaa euroa vuodessa ja vaikutus työllisyyteen noin 17 000 henkilöä vuodessa.

Keskeisiä vaatimuksia ovat korjausrakentamisen innovaatiotoimintojen kiihdytys, julkiset investointiavustukset ja verovähennykset kytkeytyen rakennusvalvonnan ohjaustoimeen, korjauskonsultoinnin osaamisen vahvistaminen, kestävien hankintojen vakiintuminen, vaihtoehtoisten korjauskonseptien kehitys ja tarjonta rahoitus- ja huoltopalveluin, käyttäjäopastuksen ja käyttäjän vaikutusmahdollisuuksien kasvattaminen sekä toimitalo-omistuksen toimintamallien kehittäminen ja vakiinnuttaminen.

Avainsanat sustainable, renovation, assessment methods, renovation concept

Preface

This report presents the main results of the research project Methods and Concepts for sustainable Renovation (MECOREN) carried out at VTT in 2009–2012.

The overall research project was a Nordic collaboration between the following research partners:

- VTT in Finland
- SINTEF in Norway
- SBI in Denmark and
- KTH in Sweden.

The objective of the project was to develop methods and concepts for sustainable renovation of buildings and groups of buildings. The project aimed at creating output to building industry and municipalities and authorities about

- optimal sustainable renovation concepts; with regard to energy concepts, the optimal solutions deal both with the demand and supply side solutions.
- impacts of alternative renovation concepts; the consideration covers all aspects of sustainability (energy, environmental impacts, social impacts in terms of occupants' health, comfort and economy)
- provision of methods and environmental information (especially concerning the environmental impacts of energy sources) in order to enable the assessment, comparisons and optimization of alternative solutions in the future in real renovation projects
- sustainable renovation strategies and methods for municipalities and private companies involved in the project.

The work for the last mentioned target was done with help of case studies that are not included in this report.

The Finnish part of the research project was done at VTT. The focus of the Finnish national part or the project was to develop understanding about the potential of alternative renovation concepts of residential buildings.

The Finnish national part of the project was funded by TEKES, VTT, Senaatti-kiinteistöt, City of Tampere, City of Helsinki and Ilmarinen. The steering group of the project was as follows:

- Kari Ristolainen, Senaatti-kiinteistöt, Chair of steering group
- Auli Karjalainen, Senaatti-kiinteistöt
- Ulla Soitinaho, City of Helsinki
- Katri Kuusinen, HKR-rakennuttaja, City of Helsinki
- Markku Kailanto, City of Tampere
- Ilmari Absetz, TEKES
- Heikki Niemi, Ilmarinen
- Heikki Kukko, VTT.

The authors of the report are:

- Tarja Häkkinen, senior principal research scientist
- Antti Ruuska, research scientist
- Sirje Vares, senior scientist
- Ilpo Kouhia, senior scientist
- Sakari Pulakka, senior scientist
- Riikka Holopainen, senior scientist.

Tarja Häkkinen was the leader of the project and also the coordinator of the Nordic project. She is the main author of the Chapters 1, 2, 3 and 13 and led the process of outlining and contents planning of the whole report. Antti Ruuska developed the calculation tool used for calculations and also performed the main part of the calculations. He is the main author of the Chapters 8, 10–12. Sirje Vares has written the Chapter 6 and is the main author of Chapter 9. Sakari Pulakka is the main author of Chapter 7. He also made the financial assessment of the selected cases (presented in Chapter 12). Ilpo Kouhia (with support of Mikko Saari) is the main author of Chapters 4 and 5. Riikka Holopainen participated in writing the Chapters 9–10.

In addition to these authors also Terttu Vainio participated to the work by collecting and providing background information used in the assessment (see Chapters 9–10). Jyri Nieminen and Jari Shemeikka also participated by giving valuable comments. Marjukka Kujanpää calculated the average environmental profiles for electricity and district heat (see Chapter 3).

Espoo 31.4.2012

Authors

Contents

1. Objectives of the research

This report presents methods and concepts for building renovation and analyses the impacts of alternative renovation scenarios on Finnish building stock in terms of energy use and carbon footprint. The focus of the study is on residential buildings. The calculations were carried out for years 2010, 2020 and 2030.

In addition to the assessment of the renovation concepts of building stock, the objective of the project was also to

- discuss and give recommendations about the use of environmental data for energy sources
- discuss and make conclusions about the significance of building materials in renovation projects from the view point of greenhouse gases and total energy use
- discuss and make recommendations about different renovations concepts
- assess and make conclusions about the economic impacts of building renovation.

The characterization of the composition of the current Finnish residential building stock formulates the starting point for the assessment. In this report, information on total floor area of the Finnish housing stock is used as the basis for the analyses. The total floor area of the Finnish housing stock was first divided into age groups based on available statistical information on residential housing stock.

In the next phase, the size and performance of buildings in different age groups were defined. The defined performance includes, for example, floor height and volume of a building, number of inhabitants, and heating, electricity and water consumption. These defined figures were then used as an input for creating exemplary buildings which were dealt with by energy calculation program WinEtana.

By using the exemplary buildings and the composition of the current housing stock, a theoretical maximum energy saving potential for the Finnish residential stock can be calculated. This was done by applying different energy saving measures to the exemplary buildings. The measures under study were: additional thermal insulation, replacing windows, replacing ventilation system and implementing solar heating.

Based on the maximum energy savings, also maximum savings in CO_2-emissions can be calculated. These calculations are based on energy production profiles in Finland.

The housing stock develops over time, so the estimation of the current housing stock is not sufficient for estimating the situation in 2020 and 2030. New construction adds to the floor area of the housing stock and obsolescence, deterioration and demoulding decrease it.

The degree of building degradation is also taken into account, since many of the energy renovations are feasible only when other renovations take place in the building. This study assumes that energy renovations are feasible only when other renovations take place. Therefore the study used an assumption that energy renovations are made only when the buildings would need renovation in any case.

2. Background

2.1 Buildings and climate change – strategies and targets

The Intergovernmental Panel on Climate Change (IPCC) synthesis report [IPCC 2007a} lists buildings as having the largest estimated economic mitigation potential among the sector solutions investigated (Figure 1). This confirms and completes an earlier statement by the United Nations Environment Programme (UNEP) Sustainable Building and Construction Initiative (SBCI) which suggests that European buildings account for roughly 40% of the energy consumption in society, contributing to significant amounts of greenhouse gas (GHG) emissions [UNEP 2007]. UNEP concludes that the building sector offers the largest single potential for energy efficiency in Europe.

The IPCC also suggests that measures to reduce GHG emissions from buildings includes three categories: reducing energy consumption and embodied energy in buildings, switching to low-carbon fuels including a higher share of renewable energy, or controlling the emissions of non-CO_2 GHG gases[IPCC 2007b]. They however divide the building-sector relevant technology assessments into two parts: presenting information for energy efficiency in new and existing buildings (demand-side building GHG reduction technologies) separate from their assessment of centralized and decentralized (or distributed) energy systems (supply-side GHG reduction technologies). Since the decision makers in building sector can influence both demand and supply side technology adoption, simultaneous conideration of trade-offs made at the building (e.g., by architects, those in construction, etc.) and regional levels (e.g., by policy developers) is warranted. For example, which technologies should be implemented first at a specific site/region and how does the first implementation impact the effectiveness of subsequent installations from cost and environmental impact standpoints, is of interest.

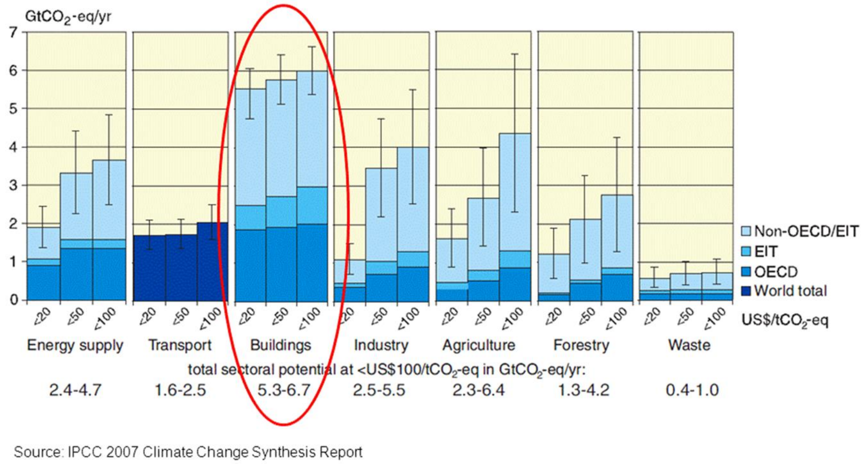


Figure 1. Buildings' estimated mitigation potential among the sector solutions investigated.

Whereas some building technologies will be effective irrespective of the installation location (e.g., use of energy efficient lighting and appliances on the demand side), the effectiveness of other technologies is site specific. Both demand and supply-side building technologies can be characterised by performance parameters that depend on the regional ecosystem or the local infrastructure [Tecnology Options 2005]. The performance parameters influence how much energy is demanded or supplied given implementation in a specific region and subsequently the GHG profile.

Europe 2020 [2012a] is the EU's growth strategy for the present decade. Sustainable growth for Europe includes:

(i) building a competitive low-carbon economy that makes efficient, sustainable use of resources
(ii) capitalising on Europe's leadership in developing new green technologies and production methods and
(iii) helping consumers make well-informed green choices.

The corresponding EU targets for sustainable growth include [Europe 2020, 2012b]:

- Reducing greenhouse gas emissions by 20% compared to 1990 levels by 2020. The EU is prepared to go further and reduce by 30% if other developed countries make similar commitments and developing countries contribute according to their abilities, as part of a comprehensive global agreement.
- Increasing the share of renewables in final energy consumption to 20%.
- Moving towards a 20% increase in energy efficiency.

In January 2008 the European Commission proposed binding legislation to implement the 20-20-20 targets. This 'climate and energy package' was agreed by the European Parliament and Council in December 2008 and became law in June 2009 [Climate Action 2010]. The national targets range from a renewables share of 10% in Malta to 49% in Sweden – in Finland the share is 38%.

According to OECD statistics, the GHG emissions in Finland in 1990 were 70 364 thousand tonnes. With its "Roadmap for moving to a competitive low-carbon economy in 2050" the European Commission [Climate Action 2011] is looking beyond the 2020 objectives and setting out a plan to meet the long-term target of reducing domestic emissions by 80 to 95% by mid-century as agreed by European Heads of State and governments. It shows how the sectors responsible for Europe's emissions – power generation, industry, transport, buildings and construction, as well as agriculture – can make the transition to a low-carbon economy over the coming decades. Figure 2 shows the corresponding targeted reduction of emissions in Finland.

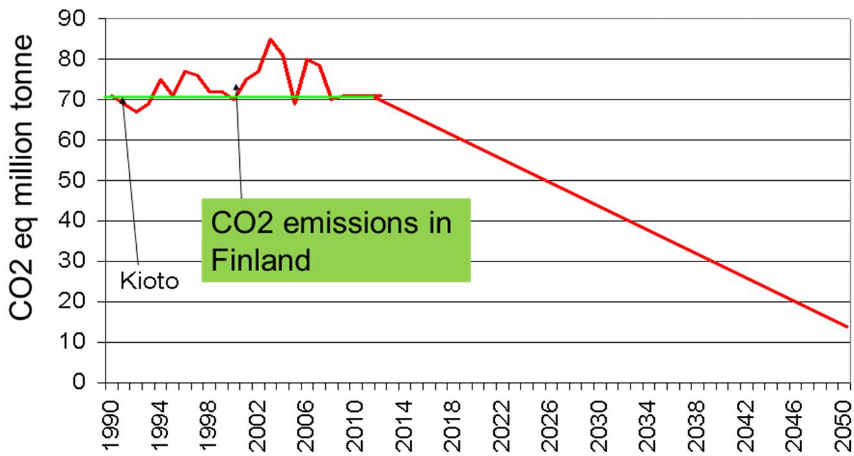


Figure 2. Targeted reduction of emissions in Finland.

According to the Roadmap [COM(2011) 112 final 2011]"The transition towards a competitive low carbon economy means that the EU should prepare for reductions in its domestic emissions by 80% by 2050 compared to 1990. The Commission has carried out an extensive modelling analysis with several possible scenarios showing how this could be done… This analysis of different scenarios shows that domestic emission reductions of the order of 40% and 60% below 1990 levels would be the cost-effective pathway by 2030 and 2040, respectively." The Roadmap specifically mentions built environment: "The built environment provides low-cost and short-term opportunities to reduce emissions, first and foremost through improvement of the energy performance of buildings. The Commission's analysis shows that emissions in this area could be reduced by around 90% by 2050, a larger than average contribution over the long-term. This underlines the importance of achieving the objective of the recast Directive on energy performance of buildings [Directive 2010/31/EU 2010]".

In Finland, the Ministry of environment has assessed that buildings' share from the total greenhouse gases (GHGs) is 32% (Figure 3). In addition, construction is responsible for causing 6% of the total GHGs in Finland (Figure 1) [Lehtinen 2012]. These results have been calculated with regard to year 2007, when the total GHG emissions were assessed to be 78 Mt CO_2.

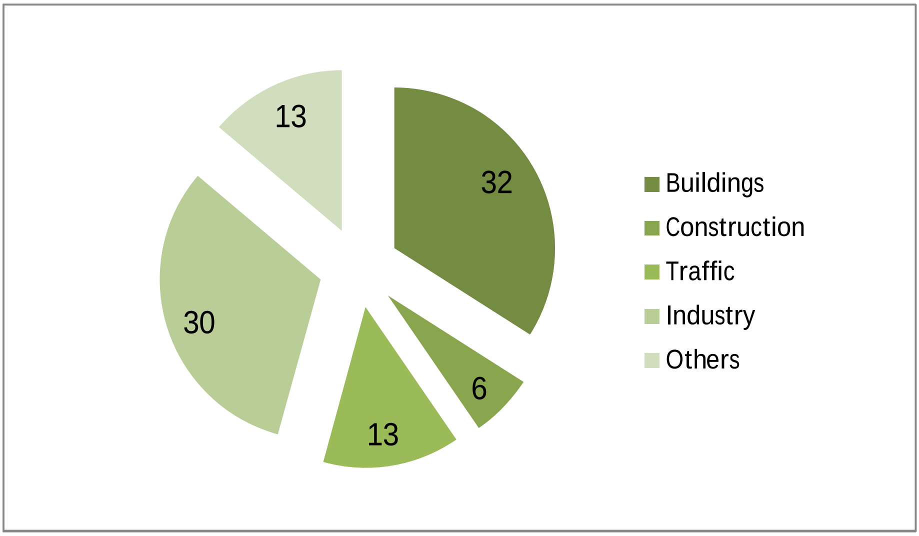


Figure 3. Division of GHG emissions in Finland.

According to OECD statistics [OECD 2012] the GHG emissions of Finland in 1990 and during the recent years have been as follows:

- 1990 70 Mt CO_2 eq
- 2007 78 Mt CO_2 eq
- 2008 70 Mt CO_2 eq
- 2009 66 Mt CO_2 eq.

In Finland the minister level working group will update the national climate and energy strategy until the end of 2012. With regard to buildings, a roadmap for nearly zero energy building by 2020 will be formulated during 2012. The requirements that will be established for building renovations will be part of the implementation of EPBD directive (2010/31/EU, see section 2.5.2).

Motiva [Statistics Finland 2010] gives the following information about the use of energy in Finland in 2010:

- the overall energy consumption was 1 463 PJ (35 Mtoe) (406 TWh)
- the corresponding final use of energy was 1004 PJ (279 TWh). This value does not include the conversion and transportation losses.
- Heating of buildings is assessed to be responsible for 25% of final use of energy (69.8 TWh).
- The electricity supply was 87.7 TWh.
- Households and farming are assessed to be responsible for the use of 28% of electricity supply (24.6 TWh).

2.2 Buildings and climate change – research results

European level studies performed out in order to assess the potential of renovation of the existing building stock with regard to savings in greenhouse gas emissions and energy consumption.

Eichhammer et al. [2009] study the overall energy saving potentials by using three different scenarios:

- Technical potential (Best available technologies and practices)
- Economic Potential – High Policy Intensity (HPI) (Cost-effectiveness for the whole country), and
- Economic Potential – Low Policy Intensity (LPI) (Cost-effectiveness for the consumer with usual market conditions).

The technological/economic restrictions on the energy savings potentials can be distinguished as follows:

- No restrictions, maximum technical potentials: what can be achieved with the best available technologies available whatever the costs and prices.
- Cost-effectiveness for the whole country: what can be achieved with the best available technologies available, which are economic on a country-wide basis (typically a discount rate of 4% could be used for energy saving investments for this case). Also barriers would be largely removed in such a context.
- Cost-effectiveness for the consumer with usual market conditions: what can be achieved with the best available technologies, which are economic for the consumer with the usual market conditions today and reflecting consumer preferences and barriers (typically a discount rate of 8–15% or higher could be used for energy saving investments for this case).

In 2030, the achievable reduction of the total unitary consumption of the residential sector including electricity is:

- 41% in the LPI Scenario
- 57% in the HPI Scenario and
- 73% in the Technical Scenario.

According to the LPI Scenario the savings arrive to 43 Mtoe (by 2030) for 27 EU countries, in the HPI Scenario the savings are of 104.8 Mtoe and in the Technical Scenario of 163.4 Mtoe.

The European research project IMPRO (Environmental Improvement Potentials of Residential Buildings) has done an overview of the environmental life cycle impacts of residential buildings in the EU-25. It conducted an analysis of the reduction of environmental impacts that could be gained with help of technical improvement options with a special focus on the main source of environmental impacts of buildings, namely energy use for space heating. The report Environmental Improvement Potentials of Residential Buildings (IMPRO-Building) (Nemry et al. 2008) assesses the environmental benefits and the costs associated with these improvement options.

IMPRO [Nemry et al. 2008] project derived a typology of the residential buildings in the 25 EU countries (EU-25). The country specific statistical data was divided in three groups: single-family houses (including two-family houses and terraced houses), multi-family houses and high-rise buildings as follows:

- Single-family houses (SI) include individual houses that are inhabited by one or two families. Also terraced houses are assigned to this group.
- Multi-family houses (MF) contain more than two dwellings in the house.
- High-rise buildings (HR) were defined as buildings that are higher than 8 storeys.

Over half of the residential buildings in Europe are single family houses (53%), while the share of multi-family buildings is 37% and the share of high-rise buildings is 10% (calculated by the number of dwellings) Nemry et al. (2008) evaluated the improvement potentials on a European level. The project studied where there are the greatest improvement potentials and how the measures should be directed in order to achieve rapid reductions on the level of whole Europe. The project also carried out cost analyses and explained to which types and zones these reductions should be directed in order to ensure minimal cost effects or maximal cost savings in the long run. From this point of view sufficient results can be gained analysing only 22 out of 53 building types (of existing buildings).

Nemry et al. [2008] derived from EUROSTAT and other references that the volume of the European residential building stock is 14.8 milliard m^2 (calculated in floor area) of which 7.38 milliard are single family houses and 7.46 milliard m^2 multifamily and high rise buildings.

- On the basis of the building models presented in Nemry et al (2008), the corresponding façade areas are 12.6 milliard m^2 for single family houses and 4.45 milliard m^2 for multifamily and high rise buildings, total area 17.1 milliard m^2 (round 80% of the building stock).
- Assessed energy consumption of the building stock was 71 701 MJ/m^2 per year (single family houses 41 348 and multifamily and high rise buildings 30 353 MJ/m^2 per year).

- Environmental impact saving potential in terms of CO_2 savings was assessed to be 360 Mt/year in total. This saving was reached through different combinations of roof insulation, external wall insulation and renewing sealings. The share of external walls from the assessed total saving was 110 Mt CO_2/year. IMPRO assesses that this can be reached when all external walls are refurbished to the level of 0.12 W/m^2K.

The European SUSREF project (Sustainable refurbishment of exterior walls and facades [SusRef] assessed the CO_2 eq and energy saving potentials of building refurbishment. Four different refurbishment concepts were dealt with: external insulation, internal insulation, cavity insulation and replacing renovation. The following assumptions were made:

- Adding new/more insulation will be relevant for 40–60% of the building stock during the next 10 years (depending on building age and climate zone).
- Stone walls will not usually be insulated outside but only in the case of an extensive sustainable renovation.
- Demolition of 5% of the present building stock will take place during the next 10 years.
- Increase of 7% of present building stock will take place during next 10 years.
- The walls already insulated or replaced by new ones have not been included to the share of potential refurbishments (SUSREF concepts). However, some energy saving actions will be done also for those during the next 10 years. When analysing the total significance of wall refurbishment it was assumed that the relative importance of those actions is so small that they have not been separately taken in account.
- There is a certain number of buildings regarding which there are either no possibilities or no needs to make external changes (25–50% of the building stock built before 1945 (because of aesthetic and cultural reasons) and 20–40% of the building stock built after 1970 (because the walls are in good condition).
- When calculating walls to be refurbished, life-cycle optimized comprehensive concept (replacing renovation) has been preferred instead of separate actions.

The following assumptions were made about the refurbishment rates:

New inner insulation	10% of total external wall areas in Europe (without cavity walls).
External insulation	20% of those external walls that in principle can be provided with an external added insulation in Europe (without cavity walls). The starting point was that there is a big part of old buildings that cannot be externally insulated because of cultural and aesthetic reasons. The starting point was also that the external insulation of those relatively new walls that are in very good condition will not be externally insulated during the coming ten years.
Cavity insulation	25% of total cavity wall areas in Europe which have not yet been insulated.
Replacing renovation	25% of the residential building stock (without cavity walls).

The assessed volumes of refurbishment are bigger than what has been the case during the last 10 years. The explanation for this choice is that it was thought that the different new steering mechanisms will accelerate the building refurbishment projects.

SUSREF assessed on the bases of calculation that that the total CO_2equ saving for the single family houses in Europe is 55.4 Mt and for the multi-story buildings 16.8 Mt per year. Thus in total the assessed saving is 72 Mt during 2011–2020 per year. This was calculated on the basis of U-value changes and heat degree days by using the proposed refurbishment concepts by the SUSREF partners from different parts of Europe.

SUSREF assessed the potential savings in energy and costs with help of using scenarios for the refurbishment of external walls. According to the basic concept (based on certain assumptions about the proportion of buildings which could undergo different kinds of refurbishments (internal, external or cavity wall insulations or extensive refurbishments)) 30% of the residential building stock will be refurbished during the next 10 years. The total investment cost was assessed to be 28 000 million euro/year allocated to the energy related refurbishment. On the other hand, the savings in energy costs were assessed to be 2 500 million euro/year. It was calculated that the change in annual Life Cycle Cost is in average -11 000 million euro within 20 years. In addition, it was assessed that the corresponding increase of labour would be 396 000 man years per year. It was also assessed that in the case of strong support (with help of different kinds of steering instruments) for refurbishment the corresponding figures might increase by 25%.

2.3 Life cycle consideration

Wide acceptance of the consideration of the life cycle is reflected in several existing building sustainability assessment methodologies and in several European sustainable building projects (i.e., [SuPerBuildings, SUSREF]). These methodologies and projects interact with standardisation activities at CEN and ISO. Notable activities are CEN/TC 350 and ISO / TC 59/ SC17, both emphasizing life cycle considerations from building inception to the end of life (see further in Section 2.3).

LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave).

The general principles on life cycle assessment (LCA) of products and services have been agreed upon and introduced with help of standardisation (ISO 14040 and ISO 14044). The life cycle of a product covers all the phases of the product life from the extraction of natural resources, through transportation, design, manufacture, distribution, assembly, use, maintenance and repair to their recycling or final disposal as waste. Life cycle assessment supports the management of environmental aspects of products and processes.

In Europe in general level, ILCD [ILCD Handbook 2010] promotes the availability, exchange and use of coherent, robust life cycle data, methods and studies for decision support in policy making and in business. The network is open to all data providers from business, national LCA projects, research groups, consultants, research projects, and others. The documentation and publication of LCI and LCIA data sets is supported by the related ILCD data set documentation and exchange format. A related data set editor allows the documentation, editing, and compliance-verification of ILCD data sets. The European Reference Life Cycle Database (ELCD) with European scope inventory data sets [LifeCycle] provide LCI data from front-running EU-level business associations and other sources for key materials, energy carriers, transport, and waste management. Focus is on data quality, consistency, and applicability. The data sets are accessible free of charge and without access restrictions. The data sets of the ELCD database will contribute key European data to the international ILCD Data Network.

EN 15978 [2011] defines a method for the environmental assessment of buildings. The standard presents the following life cycle stages for buildings:

1. Product stage, A 1–3
   - Raw material supply
   - Transport
   - Manufacturing

2. Construction process, A 4–5
   - Transport
   - Construction -installation process

3. Usa stage, B 1–7
   - Use
   - Maintenance
   - Repair
   - Replacement
   - Refurbishment

4. End of life stage, C 1–4
   - De-construction, demolition
   - Transport
   - Waste processing
   - Disposal.

The standard gives detailed rules about the systems boundaries of buildings. However, the standard does not give adequate guidance about the assessment of all important issues that affect the GHG emissions of buildings during life cycle. Especially energy source related issues that should be more precisely defined when aiming at the definition comparable assessment methods and carbon footprint (CF) benchmarks of buildings [SuPerBuildings].

2.4 Sustainable building and sustainable building indicators

ISO and CEN have developed building and construction related sustainability standards, which cover all levels and all sustainability aspects as follows:

Table 1. Suite of related International Standards for sustainability in buildings and construction works.

	Environmental aspects	Economical aspects	Social aspects
Methodological bases	ISO/15392: General principles ISO/TR 21932: Terminology		
Buildings	ISO 21929–1: Sustainability Indicators – Part 1 – Framework for the development of indicators and a core set of indicators for buildings		
	ISO/21931–1: Framework for methods of assessment of the environmental performance of construction works		
Products	ISO/21930: Environmental declaration of building products		

Table 2. The work programme of CEN/TC 350.

Framework level	EN 15643–1 Sustainability Assessment of Buildings – General Framework (TG)		
	EN 15643-2 Framework for Environmental Performance (TG)	EN 15643-3 Framework for Social Performance	EN 15643-4 Framework for Economic Performance
Building level	EN 15978 Assessment of Environmental Performance	prEN 16309 Assessment of Social Performance	Assessment of Economic Performance
Product level	EN 15804 Environmental Product Declarations		
	EN 15942 Communication Formats. Business-to-Business		
	CEN/TR 15941 Sustainability of construction works – Environmental product declarations – Methodology for selection and use of generic data		

Sustainable development of buildings and other construction works brings about the required performance and functionality with minimum adverse environmental impact, while encouraging improvements in economic and social (and cultural) aspects at local, regional and global levels [ISO 15392 2008}. Sustainable building process is defined as the overall quality of the process that enables the delivery of sustainable buildings. The three main prerequisites for sustainable building are 1) the availability of sustainable building technologies, 2) the availability of methods and knowledge for sustainable target setting, design, procurement, monitoring and management of buildings, 3) the development of sustainable building processes and the adoption the new sustainable building technologies, methods and working models. ISO 21929 [2011] defines aspects of sustainable building as follows:

Table 3. Framework: Core areas of protection, aspects of building that impact on these areas of protection and indicators that represent these aspects. The number of X.s indicates the primary areas to which the aspects have a potential impact – XX indicates primary (or direct) influence and X secondary (or indirect) influence.

Aspect		CORE INDICATORS	CORE AREAS OF PROTECTION						
			Ecosystem	Natural re-sources	Health and well-being	Social equity	Cultural heritage	Economic pros-perity	Economic capital
1	Emissions to air	Global warming potential	XX		X	X		X	
		Ozone depletion potential	XX		XX			X	
2	Use of non-renewable resources	Amount of non-renewable resources consumption by type		XX				X	
3	Fresh water consump-tion	Amount of fresh water consumption	XX	XX		X		X	
4	Waste generation	Amount of waste generation by type	X	XX	X				
5	Change of land use	Indicator measures the changes in land use caused by the devel-opment of the built environment with help of a list of criteria	XX	XX			X		
6	Access to services	Indicator measures the access to services by type with help of crite-ria	XX		X	XX			XX
7	Accessibility	Indicator measures the accessibility of building and its curtilage with help of a list of criteria				XX			
8	Indoor conditions and air quality	A set of indicators that measure the air quality and sub-aspects of indoor conditions with help of a list of measurable parameters			XX			X	
9	Adaptability	Indicator measures the flexibility, convertibility and adaptability to climate change with help of a list of criteria		XX	X				XX

Aspect		CORE INDICATORS	CORE AREAS OF PROTECTION						
			Ecosystem	Natural re-sources	Health and well-being	Social equity	Cultural heritage	Economic pros-perity	Economic capital
10	Costs	Life cycle costs						X	XX
11	Maintainability	Indicator measures the maintainability against the results of service life assessment and with help of a list of criteria or with help of expert judgement		X			X		XX
12	Safety	Indicator measures the sub-aspects of safety against the results of simulations or fulfilment of the safety related building regulations			XX				X
13	Serviceability	Indicator measures serviceability with help of a list of criteria or with help of post-occupancy evaluation						XX	
14	Aesthetic quality	Indicator measures the aesthetic quality against the fulfilment of local requirements or with help of a stakeholder judgement					XX		

2.5 European regulatory framework for sustainable buildings

2.5.1 Introduction

The main directives and regulations related to building and building products sustainability that have been recently published are as follows:

- Directive 2002/92/CE Energy Performance in Buildings Directive (EPBD).
- Directive 2009/125/EU establishing a framework for the setting of ecodesign requirements for energy-related products (ErP).
- Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.
- Regulation (EU) No 305/2011 of the European parliament and of the council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC.

2.5.2 Construction Product Regulation (EU) No 305/2011

Construction products are subject to the rules on the free movement of goods in the European Union (EU) and the rules relating to the safety of buildings, health, durability, energy economy and the protection of the environment. The Regulation (EU) No 305/2011 [2011]

- Sets out conditions for the market introduction and marketing of construction products by establishing harmonized rules on how to express the performance of construction products in relation to their essential characteristics and the use of CE marking on those products, and
- Establishes Basic Requirements for Construction Works (Annex I).

When a manufacturer decides to place a construction product on the market and that product is covered by a harmonised standard or conforms to a European Technical Assessment (ETA), it must complete a declaration of performance which contains, the following information:

- the product reference
- the systems of assessment and verification of constancy of performance of the product
- the reference number of the harmonised standard or the European Technical Assessment which has been used for the assessment
- the intended use or uses for the product
- declared performance or at least one of the essential characteristics of the product.

Harmonised technical specifications should include testing, calculation and other means, defined within harmonised standards and European Assessment Documents for assessing performance in relation to the essential characteristics of construction products.

Harmonised technical specifications include harmonised standards. These shall be drawn up by European standardisation bodies pursuant to Directive 98/34/EC. Harmonised standards serve the purpose of defining methods and assessment criteria for construction product performance. If a product is not covered by a harmonised standard, manufacturers may request an European Assessment Documents issued by Technical Assessment Bodies (TABs).

The regulation says that

- When assessing the performance of a construction product, account should also be taken of the health and safety aspects related to its use during its entire life cycle.
- Threshold levels determined by the Commission pursuant to this Regulation should be generally recognised values for the essential characteristics of the construction product in question … and should ensure a high level of protection.
- Where applicable, the declaration of performance should be accompanied by information on the content of hazardous substances in the construction product in order to improve the possibilities for sustainable construction and to facilitate the development of environmentally-friendly products.
- The basic requirement for construction works on sustainable use of natural resources should notably take into account the recyclability of construction works, their materials and parts after demolition, the durability of construction works and the use of environmentally compatible raw and secondary materials in construction works.
- For the assessment of the sustainable use of resources and of the impact of construction works on the environment Environmental Product Declarations should be used when available.
- Wherever possible, uniform European methods should be laid down for establishing compliance with the basic requirements set out in Annex I.

With regard to the development of sustainability assessment methods for building, the specific mention to life cycle environmental quality in basic requirement 3 (hygiene, health and safety), and 7 (sustainable use of natural resources) is of particular importance. The requirement 7 has generally considered by the industry as a first and important step to incorporate sustainability into building products. There is obviously a need for standardization to assess this sustainable use of resources. Task is ongoing by CEN TC 350. These newly developed standards should find a way to interact and deal with existing regulations and initiatives that require the assessment of sustainability of product.

Basic requirements

The regulation gives the following basic requirements for construction products:

Construction works as a whole and in their separate parts must be fit for their intended use, taking into account in particular the health and safety of persons involved throughout the life cycle of the works. Subject to normal maintenance, construction works must satisfy these basic requirements for construction works for an economically reasonable working life.

1. Mechanical resistance and stability

The construction works must be designed and built in such a way that the loadings that are liable to act on them during their constructions and use will not lead to any of the following:

a) collapse of the whole or part of the work
b) major deformations to an inadmissible degree
c) damage to other parts of the construction works or to fittings or installed equipment as a result of major deformation of the load-bearing construction
d) damage by an event to an extent disproportionate to the original cause.

2. Safety in case of fire

The construction works must be designed and built in such a way that in the event of an outbreak of fire:

a) the load-bearing capacity of the construction can be assumed for a specific period of time
b) the generation and spread of fire and smoke within the construction works are limited
c) the spread of fire to neighbouring construction works is limited
d) occupants can leave the construction works or be rescued by other means
e) the safety of rescue teams is taken into consideration.

3. Hygiene, health and the environment

The construction works must be designed and built in such a way that they will, throughout their life cycle, not be a threat to the hygiene or health and safety of their workers, occupants or neighbours, nor have an exceedingly high impact, over their entire life cycle, on the environmental quality or on the climate, during their construction, use and demolition, in particular as a result of any of the following:

a) the giving-off of toxic gas
b) the emissions of dangerous substances, volatile organic compounds (VOC), greenhouse gases or dangerous particles into indoor or out-door air
c) the emission of dangerous radiation

d) the release of dangerous substances into ground water, marine waters, surface waters or soil
e) the release of dangerous substances into drinking water or substances which have an otherwise negative impact on drinking water
f) faulty discharge of waste water, emission of flue gases or faulty disposal of solid or liquid waste
g) dampness in parts of the construction works or on surfaces within the construction works.

4. Safety and accessibility in use

The construction works must be designed and built in such a way that they do not present unacceptable risks of accidents or damage in service or in operation such as slipping, falling, collision, burns, electrocution, injury from explosion and burglaries. In particular, construction works must be designed and built taking into consideration accessibility and use for disabled persons.

5. Protection against noise

The construction works must be designed and built in such a way that noise perceived by the occupants or people nearby is kept to a level that will not threaten their health and will allow them to sleep, rest and work in satisfactory conditions.

6. Energy economy and heat retention

The construction works and their heating, cooling, lighting and ventilation installations must be designed and built in such a way that the amount of energy they require in use shall be low, when account is taken of the occupants and of the climatic conditions of the location. Construction works must also be energy-efficient, using as little energy as possible during their construction and dismantling.

7. Sustainable use of natural resources

The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:

a) re-use or recyclability of the construction works, their materials and parts after demolition
b) durability of the construction works
c) use of environmentally compatible raw and secondary materials in the construction works.

This Regulation entered into force in 2011. However, Articles 3 to 28, Articles 36 to 38 that set the conditions for making construction products available in the market, Articles 56 to 63, Articles 65 and 66, as well as Annexes I that sets the basic requirements for construction works and Annex II, III and V apply from 1 July 2013.

2.5.3 Directive 2010/31/EU on the energy performance of buildings

The Directive on energy performance of buildings (2002/91/EC) is the main legislative instrument at EU level to achieve energy performance in buildings. Under this Directive, the Member States must apply minimum requirements as regards the energy performance of new and existing buildings, ensure the certification of their energy performance and require the regular inspection of boilers and air conditioning systems in buildings. On 18 May 2010 a recast [Directive 2010/31/EU 2010] of The Directive on energy performance of buildings (2002/91/EC) was adopted in order to strengthen the energy performance requirements and to clarify and streamline some of its provisions.

The recast energy performance directive sets a target for all new buildings to be ‘nearly zero-energy buildings’ by 2020. The directive also deals with existing buildings undergoing a major renovation.

“Nearly zero-energy building" means a building that has a very high energy performance (as determined in accordance with Annex I). The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced onsite or nearby.

The provisions of the Directive cover energy used for space and hot water heating, cooling, ventilation, and lighting for new and existing residential and non-residential buildings.

This Directive lays down requirements as regards:

a) the common general framework for a methodology for calculating the integrated energy performance of buildings and building units
b) the application of minimum requirements to the energy performance of new buildings and new building units
c) the application of minimum requirements to the energy performance of:
   - existing buildings, building units and building elements that are subject to major renovation
   - building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are retrofitted or replaced and
   - technical building systems whenever they are installed, replaced or upgraded.
d) national plans for increasing the number of nearly zero- energy buildings
e) energy certification of buildings or building units
f) regular inspection of heating and air-conditioning systems in buildings; and
g) independent control systems for energy performance certificates and inspection reports.

The introduction of the recast directive states that

- Buildings account for 40% of total energy consumption in the Union. The sector is expanding, which is bound to increase its energy consumption. Therefore, reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce the Union's energy dependency and greenhouse gas emissions.
- Measures to improve further the energy performance of buildings should take into account climatic and local conditions as well as indoor climate environment and cost-effectiveness. These measures should not affect other requirements concerning buildings such as accessibility, safety and the intended use of the building.
- The energy performance of buildings should be calculated on the basis of a methodology, which may be differentiated at national and regional level. That includes, in addition to thermal characteristics, other factors that play an increasingly important role such as heating and air-conditioning installations, application of energy from renewable sources, passive heating and cooling elements, shading, indoor air-quality, adequate natural light and design of the building. The methodology for calculating energy performance should be based not only on the season in which heating is required, but should cover the annual energy performance of a building.
- Major renovations of existing buildings, regardless of their size, provide an opportunity to take cost-effective measures to enhance energy performance. For reasons of cost-effectiveness, it should be possible to limit the minimum energy performance requirements to the renovated parts that are most relevant for the energy performance of the building. Member States should be able to choose to define a 'major renovation' either in terms of a percentage of the surface of the building envelope or in terms of the value of the building.
- In order to provide the Commission with adequate information, Member States should draw up lists of existing and proposed measures, including those of a financial nature, other than those required by this Directive, which promote the objectives of this Directive. The existing and proposed measures listed by Member States may include, in particular, measures that aim to reduce existing legal and market barriers and encourage investments and/or other activities to increase the energy efficiency of new and existing buildings, thus potentially contributing to reducing energy poverty. Such measures could include, but should not be limited to, free or subsidised technical assistance and advice, direct subsidies, subsidised loan schemes or low interest loans, grant schemes and loan guarantee schemes. The public authorities and other institutions which provide those measures of a financial nature could link the application of such measures to the indicated energy performance and the recommendations from energy performance certificates.

Article 7 states with regard to existing buildings that

- Member States shall take the necessary measures to ensure that when buildings undergo major renovation, the energy performance of the building or the renovated part thereof is upgraded in order to meet minimum energy performance requirements set in accordance with Article 4 in so far as this is technically, functionally and economically feasible.
- Member States shall in addition take the necessary measures to ensure that when a building element that forms part of the building envelope and has a significant impact on the energy performance of the building envelope, is retrofitted or replaced, the energy performance of the building element meets minimum energy performance requirements in so far as this is technically, functionally and economically feasible.

Article 12 states with regard to existing buildings that

- The energy performance certificate shall include recommendations for the cost-optimal or cost-effective improvement of the energy performance of a building or building unit, unless there is no reasonable potential for such improvement compared to the energy performance requirements in force.
- The recommendations included in the energy performance certificate shall cover:
  a) measures carried out in connection with a major renovation of the building envelope or technical building system(s) and
  b) (measures for individual building elements independent of a major renovation of the building envelope or technical building system(s).

Member States shall adopt and publish, by 9 July 2012 at the latest, the laws, regulations and administrative provisions necessary to comply with Articles 2 to 18, and with Articles 20 and 27.

3. Environmental profiles for energy

3.1 Introduction

The starting point of MECOREN project was that the consideration of both environmental and economic impacts of building and renovation should take place on life cycle bases. When we assess and compare the advantageousness of renovation concepts from the view point of energy savings that too should happen on life cycle bases.

This Chapter presents life cycle based environmental information for alternative methods to deliver energy for the residential building stock in Finland. In addition, the Chapter discusses the problems related to assessment methods and especially the problematics of different allocation methods when assessing the environmental impacts of electricity and district heat in combined power plants (CHP). When assessing the consequential impacts of alternative renovation concepts, it is important to understand how to deal with marginal impacts. A change in energy demand may cause impacts, the significance of which cannot be calculated on the bases of average environmental impacts of energy, but on the bases of marginal impacts. This may have a significant effect on the advantageousness of alternative concepts from the view point of GHG savings.

When comparing different energy sources and methods for energy supply, attention has to be paid to the extraction of energy raw materials, combustion of fuels as well as to transfer and delivery of energy. The needed infra-structure is generally not considered because of its normally low influence on the overall environmental impacts in terms of harmful emissions and total energy consumption.

3.2 Life cycle inventory based environmental profiles for electricity and district heat

This Section presents information about the environmental impacts of electricity and district heat. The results are calculated on the basis of life cycle assessment. The Section also presents what kind of selections and decisions have to be made in the environmental assessment of energy, and discusses the significance of different selections.

Allocation

When an electricity power plant produces multi-products such as power, heat, steam, cooling or refinery products, the problem of emission allocation is encountered. Allocation is a widely recognized and challenging methodological problem in LCA, and the selection of an allocation method typically has a significant impact on the results [Soimakallio 2011]. The impact of the method of allocation is especially important in Finland because of the high rate of combined heat and power production utilization. The importance of CHP varies a lot in Europe. There are some countries like Finland and Denmark where this is very important while in other countries the percentage of gross electricity generation of combined heat and power generation is rather low (EUROSTAT [tsien030 2012]) (Table 4).

Table 4. Combined heat and power generation. Percentage of gross electricity generation. 2009. EUROSTAT.

EU 27	11.4%
Belgium	14.5%
Bulgaria	9.4%
Czech Republic	13.4%
Denmark	45.3%
Germany	13%
Estonia	9.2%
Ireland	6.3%
Greece	3%
Spain	7.5%
France	4.3%
Italy	10.2%
Cyprus	0.4%
Latvia	19.7%
Lithuania	13.7%
Luxembourg	10.1%
Hungary	20.5%
Malta	0%
Netherlands	32.1%
Austria	13.2%
Poland	17.2%
Portugal	11%
Romania	10.8%
Slovenia	6.2%
Slovakia	19.2%
Finland	35.8%
Sweden	10.5%
United Kingdom	6.5%
Norway	0.1%
Croatia	12.7%
Turkey	3.8%

This report uses two types of methods to allocate the inputs and outputs for electricity and heat in combined production – these are the so-called benefit distribution method and energy method.

The energy method allocates the emissions according to the produced energies. The benefit distribution method allocates the emissions to the products relative to their production alternatives.

When using the benefit distribution method, an alternative production method has to be defined for heat and electricity. In Finland, the common way of doing this is to use for electricity condensing power production based on coal as a production alternative typically with the efficiency of roughly 40% while the efficiency value for separate heat production is assessed to be roughly 90%. When calculating the result, the heat and electricity produced in CHP plants are allocated on the bases of the corresponding efficiencies of the alternative production methods.

On the basis of the Finnish statistics, the statistical annual efficiency was 35.9% for separate electricity production (in practice mainly only condensing power) and the efficiency for separate production of district heat was 91.0% in 2008 in Finland [Saari et al. 2010]. When using the benefit distribution method, the primary energy consumption of combined heat and power production is allocated to district heat and electricity in proportion to the efficiencies of alternative (separate) production. Thus electricity takes a significantly higher proportion of primary energy because the efficiency in separate production is much less than that of district heat.

When calculating the primary energy coefficient for district heat and electricity on the basis of these methods, the corresponding equations fheat (primary energy coefficient for district heat) and felectricity are as follows [Brock et al. 2010]:

$$f_{heat} = (((W_{CHP}/\eta_h) / (W_{CHP}/\eta_h + W_e/\eta_e)) \times Q_{CHP} + Q_h) / W_{h,net} \quad (1)$$

$$f_{electricity} = (((W_e/\eta_e) / (W_{CHP}/\eta_h + W_e/\eta_e)) \times Q_{CHP} + Q_h) / W_e \quad (2)$$

where

Q_{CHP}	annual fuel consumption in CHP production
Q_{heat}	annual fuel consumption in separate district heat production
$W_{heat, net}$	annual net production of district heat
W_{CHP}	annual heat production in CHP production
$W_{electricity}$	annual electricity production in CHP production
η_{heat}	efficiency of alternative heat production
$\eta_{electricity}$	efficiency of alternative electricity production

Saari et. al [2010] give the following primary energy coefficients for the total production of district heat and electricity and for the production of district and electricity in CHP plants.

Total production	2000	2001	2002	2003	2004	2005	2006	2007	2008	aver-age
Electricity	2.16	2.21	2.31	2.21	2.18	2.27	2.20	2.20	2.12	2.21
District heat	0.90	0.91	0.90	0.90	0.90	0.90	0.90	0.91	0.90	0.90
CHP production	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**aver-age**
Electricity	1.73	1.76	1.74	1.73	1.73	1.72	1.74	1.74	1.73	1.73
District heat	0.84	0.85	0.84	0.84	0.84	0.83	0.84	0.84	0.84	0.84

Although the difference between the primary energy factors calculated for electricity and district heat is big regarding primary energy, the difference is much less regarding GHGs (see Table 9 in Section 3.3.

Representativeness of yearly results and average results

The annual national (or regional) average production mix of the electricity may vary significantly from year to year. The variation may for instance be due to changes in electricity demand, fuel mix, technology portfolio, availability of hydro power, and net imports. For example, in Finland the annual average CO_2 emissions from electricity production between 1990 and 2002 vary by 20% from the average of the particular period [Soimakallio et al. 2011]. Consequently, using data for only one statistical year in LCA may significantly reduce the reliability and the applicability of the results to describe the situation for other years and thus an average based on an adequate number of years is recommended.

It is recommended to use average values calculated on the basis of 5 years' production mix.

Consideration of seasonal variation

The difference in annual and shorter time periods may be highly relevant, in particular when assessing the GHG emissions of a process that operates mainly or only during peak-load hours and when there is significant variation in electricity production mix between peak and base load. For example, Blum et al. [2010] studied CO_2 emission savings related to ground source heat pump systems by using an annual average German electricity mix and comparing it with a regional electricity mix for electricity consumption. Similarly, Saner et al. [2010] carried out a life cycle assessment of shallow geothermal systems used for heating and cooling by determining the GHG emissions of the electricity consumption by using the annual average electricity mix of Continental Europe and other types of annual average electricity mixes for 2006. Both studies exclude the fact that the electricity consumption of heat pump systems varies significantly between warm and cold seasons. Also, it is very likely that the electricity production mix is different in cold and warm seasons. Thus, examination of the average electricity production mixes studied and the particular consumption curves at a more detailed level, e.g. by months, may probably have influenced the results. When the electricity consumption of a process is not constant throughout a year, it may be reasonable to use figures for shorter time periods instead of annual average figures.

Holopainen et al. [2010] assessed the environmental impacts of a multi-storey residential building on the bases on LCA. Geothermal heating solution with the design power of 50% of needed maximum capacity was compared to district heating solution. The comparison was done in terms of carbon footprint with using a reference period of 50 years. The carbon footprint of district heat was calculated on the basis of district heat production in Espoo. With regard to electricity, the carbon footprint was calculated both for the average Finnish electricity production as well as for condensing power production with help of coal. The latter replaces the increased demand when the capacity is in use. The alternative scenarios were as follows:

1. The average Finnish electricity is provided both for the pump and for the added heating need because of the design power (50%)
2. The average Finnish electricity is provided for the pump but the added heating demand is produced with help of condensing power (coal)
3. The electricity demand both by the pump and by added heating is produced with help of condensing power in winter and otherwise with help od average Finnish electricity.
4. All electricity demand because of the pump and the needed additional heating is produced with help of condensing power.

The effect of the chosen scenario was very clear. On the bases of the first two scenarios, the carbon footprint (CF) of the ground heat pump solution was less than half compared to the district heat solution. On the bases of the third scenario the geothermal pump was slightly more beneficial than the other option. On the bases of the fourth scenario the geothermal pump was twice as disadvantageous in terms of CF compared to district heating option.

The consideration of seasonal difference is also important when assessing the potential of alternative renovation measures (see also next section which discusses the use of marginal values).

Consideration of marginal impacts and consequential impacts

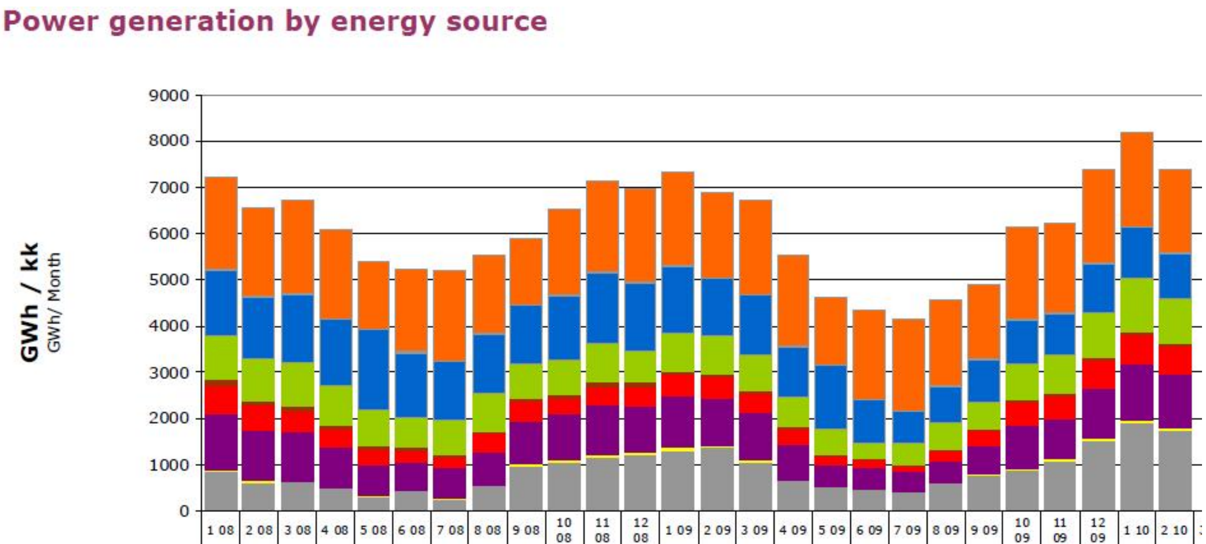
The momentary changes in the consumption of electricity influence the demand for marginal production unit. In principal, marginal data should be used to describe the impact of such changes. In reality, consequences caused by a decision to change electricity consumption may be far reaching. Attributional LCA is defined by its focus on describing the environmentally relevant physical flows to and from a life cycle and its subsystems. Consequential LCA is defined by its aim to describe how environmentally relevant flows will change in response to possible decisions [Finnveden et al. 2009]. According to Curran et al. [2005] attributional and consequential LCIs are modelling methods which respond to different questions: attributional LCIs attempt to answer ''how are things (pollutants, resources, and exchanges among processes) flowing within the chosen temporal window?'' while consequential LCIs attempt to answer ''how will flows change in response to decisions?'' The number of consequential LCA studies has increased recently, but only a few studies have systematically aimed at determining marginal data for electricity consumption [Soimakallio et al. 2011].

The consideration of the seasonal changes is important especially when assessing the effects of such energy-saving renovation concepts that do not cause a constant reduction in the demand for delivered energy but bring about savings that vary along seasons. Many of the energy-saving renovation options have different saving potentials in different seasonal periods. This is partly based on the fact that in cold regions buildings' energy demand naturally also varies along the yearly seasons. While structural and HVAC related solutions like added insulation of building envelop, renewal of windows, and ventilation heat recovery mainly cause savings in energy use during heating seasons, solutions that help to save water consumption (including hot water) cause savings in energy consumption through the year. Utilization of solar energy for heating water or for the production of power, however, causes savings that take mainly place in spring, summer and autumn. Thus when assessing the environmental impacts of the savings, the use of the monthly average values of heat and electricity instead of annual average values, should be considered. Or even more, analogically to what was done by Holopainen et al. [2010] in connection of new building (see the explanation before), the impacts of seasonal savings during winter time could be assessed with help of marginal values using condensing power production based on coal. This would mean that the assessed savings in terms of GHGs because of renovation would be significantly bigger than the estimates based on average values.

On the other hand, the long-term impact of building renovation goes against the use of marginal impacts. The impacts are typically assessed with using a time period of 20–50 years. However, in situations, where – for example a municipality – is looking for alternatives to diminish the demand for regional energy production having high carbon footprint, the use of marginal impacts may be a reasonable choice also when assessing the impacts of building renovation.

The following Figure 4 presents the monthly power generation by energy source. The demand is bigger than supply which is thus increased with help of import. This takes place mainly from Russia and is mainly based on the use of fossil fuels. The second Figure 5 presents the generation of conventional thermal power but it also shows information about the export of electricity. The third Figure 6 shows the production of separate thermal power by fuels. On the bases of this information it can be assumed that changes in the demand up to a certain amount can primarily be responded with help of changes in fossil fuel based power generation also in the cases where the reduction takes place in warm seasons.

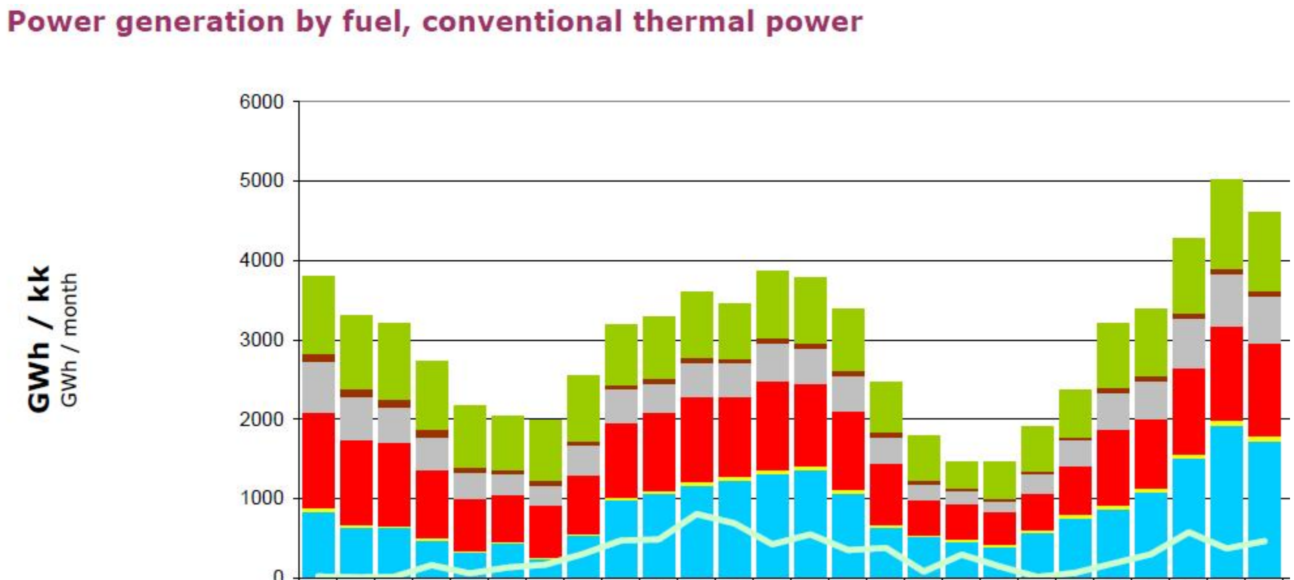
One option worth of consideration would be to always use monthly average values for the impact assessment of alternative energy saving solutions. When the potential change in power generation methods because of change in demand is known, this should be taken into account. In that case, the environmental impact of the increase or decrease in demand would be calculated by using the environmental profile of the relevant power generation method. The use of as realistic impact models as possible is recommended, when assessing the potential of significant changes.



	1 08	2 08	3 08	4 08	5 08	6 08	7 08	8 08	9 08	10 08	11 08	12 08
ydinvoima - Nuclear	2002	1898	2030	1958	1458	1803	1961	1680	1435	1849	1956	2020
tuulivoima - Wind	31	26	24	14	13	15	12	17	16	34	29	28
vesivoima - Hydro	1404	1337	1480	1394	1755	1397	1252	1272	1263	1375	1535	1448
puu ja muu bio - Bio	967	928	951	867	772	666	758	828	750	773	838	692
muu ei-bio - Others	94	92	94	85	67	51	56	47	58	70	63	63
turve - Peat	650	546	457	420	342	265	243	389	422	361	422	430
maakaasu - Natural gas	1196	1075	1043	863	661	595	663	735	944	981	1072	1003
öljy - Oil	41	34	31	27	23	22	22	29	37	39	43	41
hiili - Coal	845	633	630	473	312	435	242	531	978	1061	1174	1234
yhteensä - Total	7231	6569	6740	6101	5403	5249	5210	5526	5902	6544	7130	6957

	1 09	2 09	3 09	4 09	5 09	6 09	7 09	8 09	9 09	10 09	11 09	12 09	1 10	2 10
ydinvoima - Nuclear	2019	1828	2026	1956	1472	1922	1974	1853	1567	2002	1943	2021	2020	1825
tuulivoima - Wind	28	20	22	23	22	16	14	19	33	23	29	26	24	20
vesivoima - Hydro	1418	1240	1283	1074	1360	943	685	796	915	919	852	1079	1102	946
puu ja muu bio - Bio	839	817	772	618	558	318	452	553	578	798	844	936	1125	989
muu ei-bio - Others	63	62	68	61	44	35	33	36	47	60	62	63	67	64
turve - Peat	475	452	444	343	200	162	134	243	324	476	483	623	652	593
maakaasu - Natural gas	1119	1037	994	771	444	456	419	464	611	946	866	1084	1187	1167
öljy - Oil	46	48	45	33	25	28	33	33	40	48	50	60	69	65
hiili - Coal	1323	1362	1067	635	516	458	389	577	763	873	1085	1508	1918	1733
yhteensä - Total	7330	6868	6722	5514	4642	4338	4133	4572	4876	6145	6213	7400	8165	7402

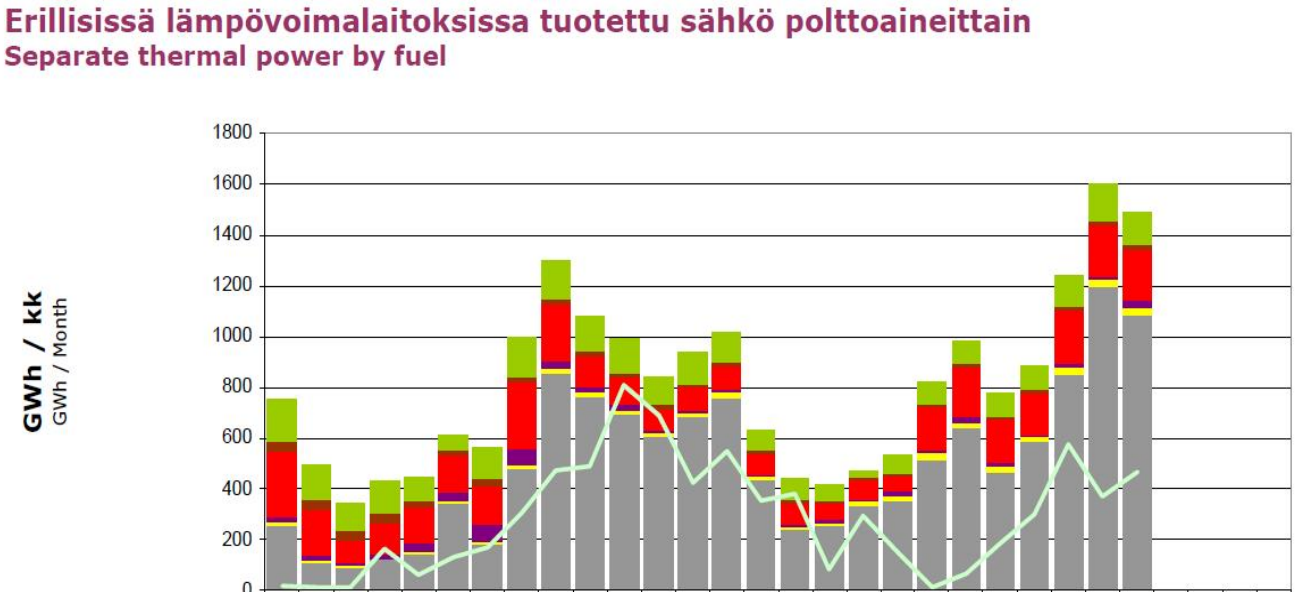
Figure 4. Power generation by source (source Statistics Finland).



	1 08	2 08	3 08	4 08	5 08	6 08	7 08	8 08	9 08	10 08	11 08	12 08	1 09
puu ja muu bio - Bio	967	928	951	867	772	666	758	828	750	773	838	692	839
muu ei-bio - Others	94	92	94	85	67	51	56	47	58	70	63	63	63
turve - Peat	650	546	457	420	342	265	243	389	422	361	422	430	475
maakaasu - Natural gas	1196	1075	1043	863	661	595	663	735	944	981	1072	1003	1119
öljy - Oil	41	34	31	27	23	22	22	29	37	39	43	41	46
hiili - Coal	845	633	630	473	312	435	242	531	978	1061	1174	1234	1323
(sähkön vienti - Electricity Exports)	20	11	16	163	59	134	169	305	473	487	808	689	425
yhteensä - Total	3793	3308	3206	2735	2177	2035	1985	2558	3189	3285	3611	3462	3864

	2 09	3 09	4 09	5 09	6 09	7 09	8 09	9 09	10 09	11 09	12 09	1 10	2 10
puu ja muu bio - Bio	817	772	618	558	318	452	553	578	798	844	936	1125	989
muu ei-bio - Others	62	68	61	44	35	33	36	47	60	62	63	67	64
turve - Peat	452	444	343	200	162	134	243	324	476	483	623	652	593
maakaasu - Natural gas	1037	994	771	444	456	419	464	611	946	866	1084	1187	1167
öljy - Oil	48	45	33	25	28	33	33	40	48	50	60	69	65
hiili - Coal	1362	1067	635	516	458	389	577	763	873	1085	1508	1918	1733
(sähkön vienti - Electricity Exports)	551	353	380	81	295	147	15	67	184	299	577	372	465
yhteensä - Total	3780	3391	2462	1788	1457	1460	1905	2361	3201	3389	4274	5019	4612

Figure 5. Power generation by fuel, conventional thermal power (Source Statistics Finland).



	1 08	2 08	3 08	4 08	5 08	6 08	7 08	8 08	9 08	10 08	11 08	12 08
puu ja muu bio - Bio	163	136	110	128	93	61	124	155	149	138	140	110
muu ei-bio - Others	38	38	37	35	30	23	27	22	26	24	16	14
turve - Peat	264	187	84	126	141	144	151	259	221	118	109	89
maakaasu - Natural gas	17	15	15	17	32	32	71	66	30	19	19	8
öljy - Oil	14	9	6	8	7	10	9	16	21	18	17	14
hiili - Coal	257	111	91	119	145	343	181	480	855	766	694	607
yhteensä - Total	752	496	343	432	448	614	564	997	1302	1082	995	843
(sähkön vienti - Electricity Exports)	20	11	16	163	59	134	169	305	473	487	808	689

	1 09	2 09	3 09	4 09	5 09	6 09	7 09	8 09	9 09	10 09	11 09	12 09	1 10	2 10	3 10	4 10	5 10	6 10
puu ja muu bio - Bio	124	116	77	82	62	26	74	87	87	89	92	122	144	134				
muu ei-bio - Others	14	14	16	16	13	11	9	11	15	15	15	14	14	13				
turve - Peat	93	93	80	82	67	74	60	167	198	165	159	211	207	200				
maakaasu - Natural gas	7	11	5	9	10	9	14	14	18	15	9	16	7	35				
öljy - Oil	16	20	17	12	11	18	23	23	25	22	21	25	31	30				
hiili - Coal	686	761	437	239	254	334	354	518	639	469	587	852	1196	1082				
yhteensä - Total	940	1016	632	440	418	471	534	820	982	775	883	1241	1599	1492				
(sähkön vienti - Electricity Exports)	425	551	353	380	81	295	147	15	67	184	299	577	372	465				

Figure 6. Separate thermal power per fuel (Source Statistics Finland).

Chapter 11 of this report gives assessment results about the environmental impact of alternative renovation methods. One of the assessment results shows that, if all the existing detached houses with electrical heating were converted to ground heating by 2030, the total demand for delivered electricity and total release of GHGs of detached houses would decrease by

- 8.6 TWh
- 1.8 Mt GHG.

However, assuming that half of 8.6 TWh is produced in condensing power plants in winter, the saving becomes 4.5 Mt GHGs, if we use marginal values for the GHGs of electricity (meaning an emission value of roughly CO_2e = 1000 g/kWh instead of roughly CO_2e = 300 g/kWh).

A principal analysis about the effect of selected base cases on peak demand for electricity

This section presents a principal analysis about what happens to the peak demand for electricity when buildings are renovated with help of alternative methods. The cases looked at are as follows:

Case 1 Present heat source for heating of spaces and water: district heat
Method 1: additional insulation of building envelop
Method 2: utilization of ground heat with help of ground heat pump
Method 3: utilization of photo voltage and solar heating

Case 2 Present heat source for heating of spaces and water: direct electric heating
Method 1: additional insulation of building envelop
Method 2: utilization of ground heat with help of ground heat pump
Method 3: utilization of photo voltage and solar heating

Case 3 Present heat source for heating of spaces and water: oil heating
Method 1: additional insulation of building envelop
Method 2: utilization of ground heat with help of ground heat pump
Method 3: utilization of photo voltage and solar heating
Method 4: change of fuel to wood pellets.

The principal assessment is based on the results about the power generation in 2009 and 2010. However, the assessment takes into account that there is significant production of separate thermal power with help of fossil fuels also in summer. Thus the rough assessment considers that all additional use of electricity and savings in electricity can be calculated with help of marginal values. The rough values for GHG used in the assessment are (in g/kWh) 330 for electricity, 970 for coal based condensing power, 250 for district heat and 330 for oil and 10 for wood.

Table 5. Rough assessment of the effect of the change in heating energy source for electricity peak demand during winter and for average carbon footprint.

- Red: electricity peak demand increase
- Green: electricity peak demand decreases
- Yellow: no essential change in electricity peak demand

		Comments	Effect on electricity peak demand during winter	Effect on average CF
Case 1 Present heat source: district heat	Additional insulation of building envelop	Additional insulation decreases the demand for district heat (highest decrease in coldest months in winter). When ventilation is improved at the same time, there is increase in average demand for delivered electricity.		
	Utilization of ground heat with help of heat pumps	Although the demand for delivered energy decreases, the CF increases if the increased electricity is calculated on the basis of marginal values.		
	Utilization of photo voltage and solar heating	Although the demand for delivered electricity decreases in average, there is no decrease during the coldest winter months.		
Case 2 Present heat source: direct electric heating	Additional insulation of building envelop	When ventilation is improved at the same time, the decrease may remain low.		
	Utilization of ground heat with help of heat pumps			
	Utilization of photo voltage and solar heating			
Case 3 Present heat source: oil heating	Additional insulation of building envelop	When ventilation is improved at the same time, there is some increase in peak demand for delivered electricity.		
	Utilization of ground heat with help of heat pumps	The decrease in CF is ineffective when the increased electricity is calculated on the basis of marginal values.		
	Utilization of photo voltage and solar heating			
	Change of fuel to wood pellets			

Consideration of regional differences

Some proportion of the electricity consumed within a country is often produced outside the boarders of the country. Correspondingly, a share of the produced electricity may be exported to other neighbouring countries. Thus the average national figures do not necessarily reflect the GHG and other emission profiles of the countries' electricity consumption if they are not adjusted by exports and imports of the electricity. However, it may prove difficult to find appropriate data which would correspond objectively to the electricity trade by taking into account the precise timing of the trade. The problem caused by the electricity trade between countries can be reduced or avoided by determining a geographical area larger than a country (e.g. even the whole EU). However, then the electricity consumed within a country does not well reflect the characteristics of the electricity production mix and transmission of that country. As electricity transmission capacity is also limited within a country, it may sometimes be reasonable to consider regions smaller than a country in determining the appropriate electricity production mix. Then the problem of considering the electricity transmission between regions is again encountered [Soimakallio 2011].

The European Life Cycle Database [ELCD 2010] database gives Life Cycle Inventory (LCI) results for the electricity supply in different European countries and for EU 27. Energy carrier mix information based on official statistical information including import and export. Detailed power plant models were used, which combine measured emissions plus calculated values for not measured emissions of e.g. organics or heavy metals. Each country provides a certain amount of electricity to the mix. The electricity is either produced in energy carrier specific power plants and / or energy carrier specific heat and power plants (CHP). Each country specific fuel supply (share of resources used, by import and / or domestic supply) including the country specific energy carrier properties (e.g. element and energy contents) are accounted for. Furthermore country specific technology standards of power plants regarding efficiency, firing technology, flue-gas desulphurisation, NOx removal and dedusting are considered. The data set considers the whole supply chain of the fuels from exploration over extraction and preparation to transport of fuels to the power plants. For the combined heat and power production, allocation by exergetic content is applied. For the electricity generation and by-products, e.g. gypsum, allocation by market value is applied due to no common physical properties. Within the refinery allocation by net calorific value and mass is used. For the combined crude oil, natural gas and natural gas liquids production allocation by net calorific value is applied. Some key figures of the assessment result are presented in Table.

Table 6. LCI result for electricity for EU 27 according to ELCD [2010].

Inputs	
Brown coal (11.9 MJ/kg LHV)	1.39 MJ (LHV)
Crude oil (42.3 MJ/kg LHV)	0.720 MJ (LHV)
Hard coal (26.3 MJ/kg LHV)	2.14 MJ (LHV)
Natural gas (44.1 MJ/kg LHV)	1.83 MJ (LHV)
Peat (8.4 MJ/kg LHV)	0.0242 MJ (LHV)
Primary energy from geothermics	0.0245 MJ (LHV)
Primary energy from hydro power	0.610 MJ (LHV)
Primary energy from solar energy	0.102 MJ (LHV)
Primary energy from wind power	0.119 MJ (LHV)
Uranium	5.00 MJ (LHV)
Wood (14.7 MJ/kg LHV)	0.0000505 MJ (LHV)
Outputs	
Electricity	3.6 MJ (1 kWh) (net calorific value)
CO2	0.558 kg
CH4	0.00108 kg
N2O	0.0000134 kg
NO2	0.00105 kg
SO2	0.00328 kg

When Finnish electricity supply mix was assessed in this project, country-based net imports were calculated and included in the balance sheet. Exports from Sweden and Norway exceeded imports and thus net import from these countries was assessed to be zero (avoided import was not calculated) [Kujanpää 2011].The Finnish electricity supply mix in 2008 is presented in Table 7. Roughly 31% of domestic electricity supply was based on renewable energy sources, 29% on fossil energy sources and 26% on nuclear power in 2008. Roughly 18% of the total supply is covered with imported electricity, mainly from Russian, whereas circa 4% of the supplied electricity was exported, mainly to Sweden.

Table 7. Finnish electricity supply mix in year 2008.

Fuel	[GWh]	[%]
Coal	8493	10%
Peat	5193	6%
Waste	469	1%
Biomass + biogas	9867	11%
Natural gas	11231	13%
Oil	386	0%
Nuclear	22958	26%
Hydro	17112	19%
Wind + solar	265	0%
Other sources	61	0%
Net import	12770	14.4%

Import and export figures for years 2005 and 2010 are presented in Table 8. The numbers show that the import to Finland from Russia is clearly the biggest, and the amounts of imported electricity from Estonia are growing.

Table 8. Electricity imports and exports in years 2005 and 2010 [Energiateollisuus].

GWh	2005	2010
Import	17948	15719
Russia	11 314	11638
Sweden	6470	2000
Norway	164	114
Estonia	0	1967
Export	933	5218
Russia	0	0
Sweden	802	4816
Norway	131	156
Estonia	0	246

3.3 Recommended environmental profiles for electricity and district heat and other energy sources

Environmental profiles for electricity and district heat

This section gives the calculated environmental profiles for heat and electricity as an average value for 2004–2008 and for 2008.

The models built for the calculation of the average electricity supply and heat production include fuel extraction (heavy fuel oil, hard coal, natural gas extraction, greenhouse gas emissions from peat manufacturing), electricity and heat production both in electricity and CHP plants, net imports and transmission losses. The used allocation methods for CHP are energy allocation and benefit distribution. Due to lack of data, separate heat production is taken into account only for heavy fuel oil (78% of heat produced with oil is from separate production in 2008). Other fuels are mainly used in CHP plants (75–95% of heat produced in CHP) and the shares of separate production are smaller. The assessment covers the years 2004–2008 [Kujanpää 2011].

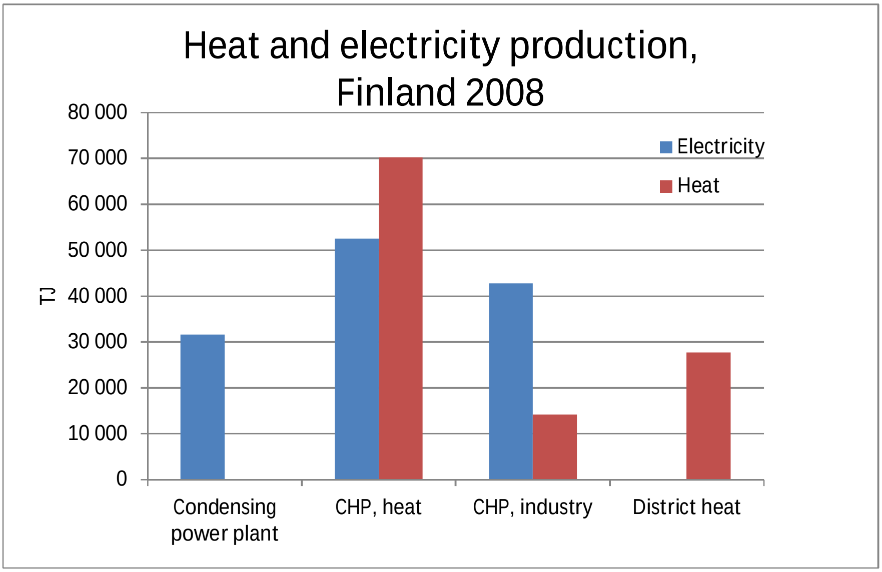


Figure 7. Heat and electricity production, Finland 2008.

Table 9. LCA based environmental profiles for average Finnish electricity (considering net imports).

	Benefit		Energy	
	Electricity	District heat	Electricity	District heat
CO2 fossil, kg/MWh	309	236	222	273
CO2 biogenic, kg/MWh	121	134	67.5	160
CH4, kg/MWh	0.821	0,364	0.709	0,424
N2O, kg/MWh	0.000654	0.000397	0.000523	0.000448
GHG, kg/MWh	330	245	240	283
Materials, mainly fossil, kg/MWh	113	69.3	90.8	79,7
Materials, wood, kg/MWh	25.5	52.7	25.8	63.4

The greenhouse gases of electricity produced in condensing power plant has been earlier assessed to be 966 g/kWh [Holopainen et al. 2010]. The assessment is based on the information received from two power plants (Fortum Meri-Pori and Fortum Inkoo).

In addition to the results that describe the average for years 2004–2008, the LCI based environmental information for electricity and heat produced in 2008 was also calculated. The average profile is recommended for use but the profile for year 2008 is presented here because it was originally used in the assessment tool developed within MECOREN (see Chapter 12). This was calculated according to the Finnish production (Figure 8) and used fuels (Figure 9). The information is based on the data from the Finnish energy industry and Statistics Finland.

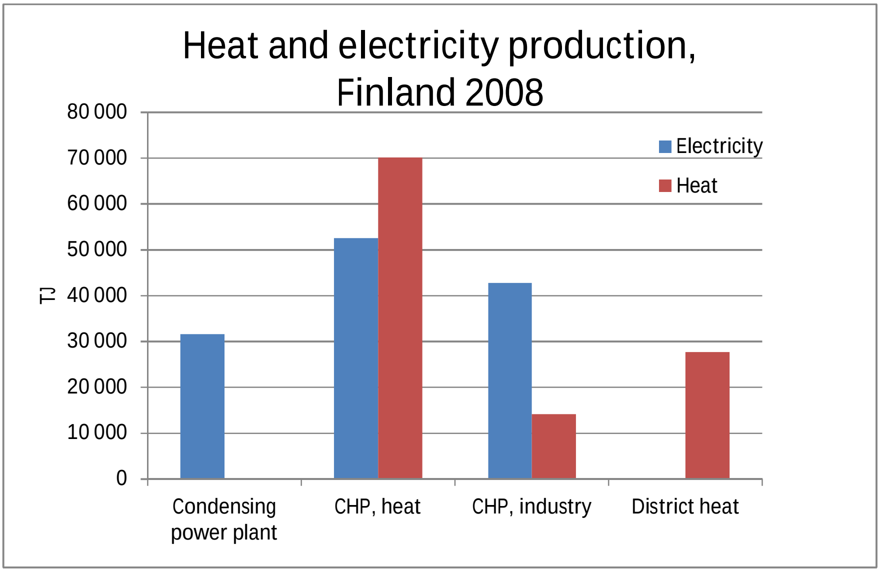


Figure 8. Heat and electricity production in 2008 in Finland.

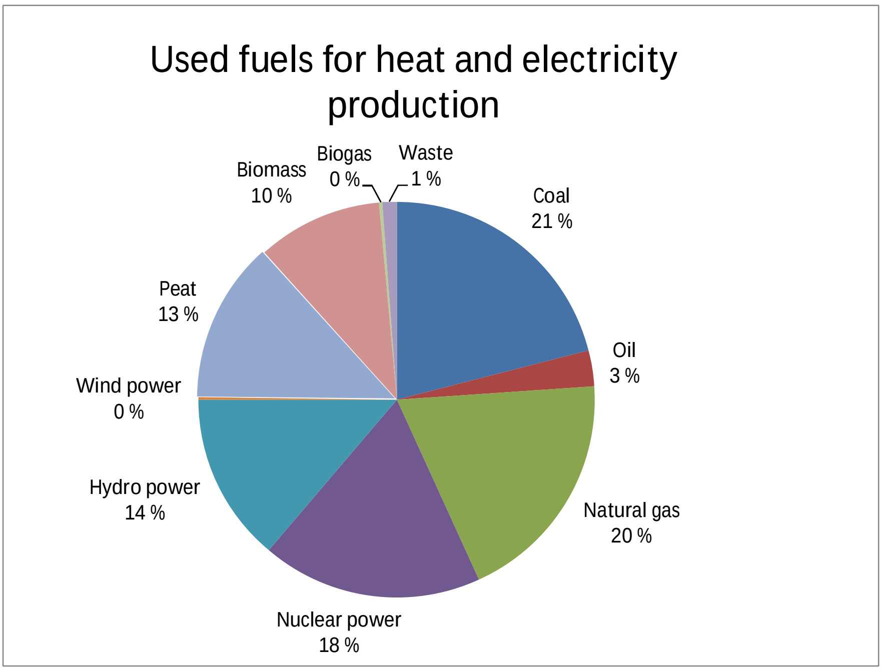


Figure 9. Energy sources supplied for heat and electricity production in Finland 2008.

The emission factors for fuel combustion are based on IPCC's values for stationary combustion [IPCC 2006a] and fuel procurement is based on National Renewable Energy Laboratory data "Energy and emission factors for energy use in buildings", 2007 [Deru & Torcellini 2007]. The emissions for heat and electricity produced in CHP plants (co-generation method) were calculated according to the benefit distribution method. In this method emissions are allocated to power and heat in relation to the assumed alternative production forms where alternative electricity is produced in condensing power plants with efficiency factor 39% and heat produced in separate heating plant with boiler efficiency of 90%. In addition to the CHP production also stand alone power and district heat plants were taken into account. Results are presented in Table 10. Table 10 also presents the corresponding values for oil and wood heating. The values presented in Table 10 were used as starting values in the MECOREN tool presented in Chapters 10–12. The next section presents the updated values for oil and wood heating. These are calculated by using the ELCD values for pre-combustion impacts.

Table 10. Environmental profiles for different heating methods.

The emission factor for wood procurement is based on the Finnish forest management and wood logging (plantation, cultivation, forestry, clearing, felling). Emissions are allocated between the sawn timber and bark, dust, chip according to their dry mass. The CO_2 emission from wood combustion is based on the assumption that during the timber growth the CO_2 uptake is of the same magnitude than the release during combustion. Other greenhouse gas emissions (CH_4 and N_2O) are based on IPCC's data for stationary combustion.

Emissions	Electricity	District heat	Oil	Wood and other biomass
CO_2, g/kWh	218	205	317	4
CH_4, mg/kWh	201	140	454	108
N_20, mg/kWh	4	4	2.9	14.4
CO_2 eq, g/kWh	224	210	327	10
Energy				
Fossil energy, MJ/kWh	3.9	3.1	4.11	0.1
Renewable energy, MJ/kWh	1.5	0.7		3.99
Raw-materials				
Non-renewable, g/kWh	109	103	84	
Renewable, kg/kWh				225

Environmental profiles for oil and wood heating

Environmental impact for fossil fuel procurement (pre-combustion) is recommended to be based on ELCD data [LCA 2010]. All ELCD data for fuels represents cradle to gate inventory. The data set represents the region specific situation focusing on the main technologies, the region specific characteristics and import statistics.

Table 11 shows the density and net calorific values for light fuel oil, heavy fuel oil, diesel oil, natural gas, and coal. The pre-combustion values for energies and raw-materials are presented in Table 12. Emission factors are presented in Table 13.

Table 11. Densities and net calorific values for fuels.

	Light fuel oil	Heavy fuel oil	Diesel oil	Natural gas	Coal
Density (kg/dm^3)	0.84	0.98	0.84	0.000722	
LHV (MJ/kg)*	43	40	43	48	27

* LHV is a net calorific value, based on IPCC 2006 Guidelines Chapter 1 [IPCC 2006b]

Table 12. Non-renewable and renewable energy and raw materials for pre-combustion of fuels. Pre-combustion values based on the ELCD database.

	Non-renewable energy (MJ/kg)	Renewable energy (MJ/kg)	Non-renewable materials (kg/kg)	
Light fuel oil	50.2	0.0671	0.165	-
Heavy fuel oil	44.2	0.0559	0.114	-
Diesel oil	50.4	0.0673	0.139	-
Natural Gas (desulphurised)	50.3	0.00331	0.118	-
Coal	27.7	0.0219	4.93	-

Table 13. Pre-combustion emission factors for fuels (calculated according to the ELCD data except for wood and peat).

	CO_2	CH_4	N_2O	CO_2e *	
Light fuel oil	7.00	0.0777	0.000162	9.0	g/MJ
Heavy fuel oil	6.73	0.0735	0.000156	8.6	g/MJ
Diesel oil	7.02	0.0781	0.000162	9.0	g/MJ
Natural Gas	5.95	0.1439	0.000114	9.6	g/MJ
Coal	3.93	0.294	0.000188	11.3	g/MJ
Peat	4.0	-	-	-	g/MJ
Wood	1.0	-	-	-	g/MJ

* CO2e is a carbon dioxide equivalent. It is calculated according to emission coefficients CO_2 = 1, CH4 = 25 and N20 = 298 (IPCC WG1 report, July 2007, Chapter 2, page 212, Table 2.14, http://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/ar4-wg1-chapter2.pdf).

Stationary combustion

Emission factors for stationary combustion in the category commercial buildings are based on IPCC Guidelines/Stationary combustion [IPCC 2006a]. Values are given on the basis of net calorific values. The emissions factors used for fuels for energy industry and residential category use are as follows (Table 14).

Table 14. Emission factors for stationary combustion in the category commercial buildings Values are given in net calorific value basis. Data is based on IPCC Guidelines/Stationary combustion [IPCC 2006a].

	CO_2	CH_4	N_2O	CO_2e **	$CO2_{etot}$***
Fuel type	g/MJ	g/MJ	g/MJ	g/MJ	g/MJ
Default emission factors in the energy industries					
Light heating oil	74.1	0.003	0.0006	74.4	83.3
Heavy fuel oil	77.4	0.003	0.0006	77.7	86.3
Diesel oil	74.1	0.003	0.0006	74.4	83.4
Natural gas	56.1	0.001	0.0001	56.2	65.7
Bituminous coal	94.6	0.001	0.0015	95.1	106.4
Lignite coal	101	0.001	0.0015	101.5	112.8
Peat	106	0.001	0.0015	106.5	117.8
Wood or other solid biomass	0 *	0.030	0.004	1.9	2.9
Default emission factors in the residential categories					
Light heating oil	74.1	0.010	0.0006	74.5	83.5
Heavy fuel oil	77.4	0.010	0.0006	77.8	86.4
Diesel oil	74.1	0.010	0.0006	74.5	83.6
Natural gas	56.1	0.005	0.0001	56.3	65.8
Bituminous coal	94.6	0.010	0.0015	95.3	107
Lignite coal	101	0.010	0.0015	102	113
Peat	106	0.3	0.0014	114	
Wood or other solid biomass	0 *	0.300	0.004	8.7	9.7

*Biomass related CO_2 emissions are neglected because considering the initial binding of CO2 from the atmosphere during photosynthesis.
** Carbon dioxide equivalent.
*** Total carbon dioxide equivalent including the pre-combustion value.

3.4 Future trends in energy production in Finland

Motiva [Statistics Finland 2010] gives the following information about the use of energy in Finland in 2010:

- the overall energy consumption was 1 463 PJ (35 Mtoe) (406 TWh)
- the corresponding final use of energy (was 1004 PJ(279 TWh). This value does not include the conversion and transportation losses.

- Heating of buildings is assessed to be responsible for 25% of final use of energy (69.8 TWh).
- The electricity supply was 87.7 TWh.
- Households and farming are assessed to be responsible for the use of 28% of electricity supply (24.6 TWh).

This section describes the assumptions which are made concerning the future development of heating energy production in Finland.

The future changes in the demand for delivered electricity compared to the supply and the changes in the methods of production should be considered in the environmental assessment of building renovations.

On the bases of the baseline scenario presented in Energy Visions 2050 [Energy Visions 2050], the total electricity supply in Finland will increase slightly over 100 TWh by 2020 and either increase to almost 120 TWh by 2050 or remain approximately at the same level until 2050 (boosted scenario).The possibility for slow growth can be attributed partly to the considerable shift in the structure of economy towards less energy-intensive economic activities, and partly to the optimistic assumptions concerning energy efficiency improvements in the boosted scenario variants.

The potential for increasing hydro power production is almost fully utilised. The share of wind power may increase to 6–17% (Energy Visions 2050).

The following Table presents the vision presented by the Finnish energy Industries [Tanner-Faatinen 2010]. The following Figure presents an assessment about the changes in energy sources for the production of electricity.

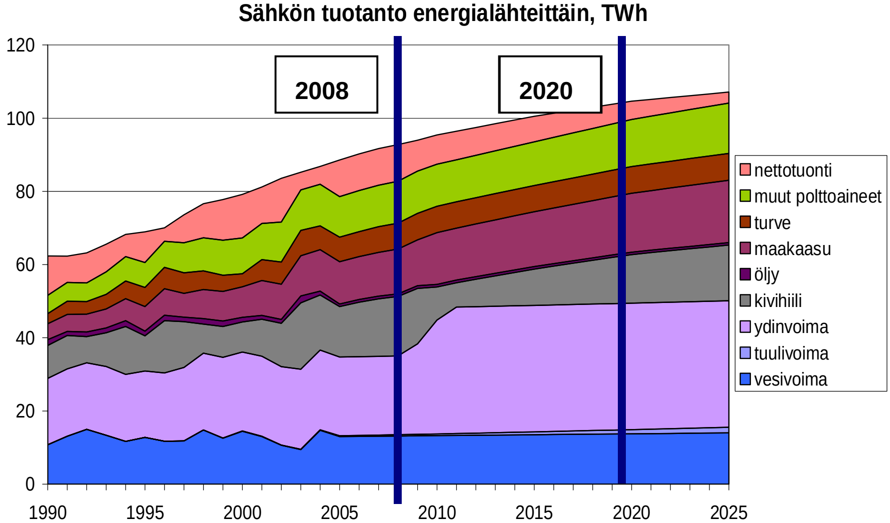


Figure 10. The production of electricity from different energy sources [Suomen eneriga- ja ilmastostratefian skenaario].

Table 15. Net supply of electricity (2008 represents realization in 2008) [Tanner-Faatinen 2010].

Method of production	2008 TWh/a	2015 TWh/a	2030 TWh/a	2050 TWh/a	2050 TWh/a
Hydro power	16.8	14	14	15	16–18
Wind power	0.26	6	9.5	9.5	15–20
Nuclear power	22	36	38	38	45–60
CHP Total	26.5	25	25.5	27.5	- 30
CHP Industry	11.9	10	11.5	11.5	
CHP Heat	14.6	15	14	16	
Production without separate condensing production	65.7	81	87	90	105–135
Demand for delivered electricity	87.2	96	106	117	
Demand beyond the supply with help of hydro, wind and nu-clear power and CHP	**21.5**	**15**	**19**	**27**	**10–15**
Separate production of electricity	8.8	6	9	12	10–15
Net import	12.8	9	10	15	

On the bases of the scenario presented in Table, the CF of average electricity would only decrease by roughly 15% by 2030 if the fuel base remains the same and no carbon capture and storage technologies are taken in use. The possibilities to make the decrease of CF bigger include the change of fuels and additional utilization of biomass, mobilization of carbon capture and storage technologies, and higher development of wind power and nuclear power.

In Energy Visions 2050 [Energy Visions 2050] assumptions were made about the limitations in bio-energy resources and unsuitability of CCS with CHP technologies (apart from the largest natural gas combined cycle plants). Thus one possibility is that the CHP technologies start to decrease with higher prices of emission allowances. However, this scenario might lead to in-sufficient production capacity in winter.

However, the Finnish Ministry of Employment and Economy (TEM) has presented also lower estimates for the future demand. On the basis of visions concerning the economic situation and structural change of industry, it may be that the demand for electricity in 2020 is not more than 91 TWh (and 100 TWh in 2030). And if the planned measures for improved energy efficiency will be successful, the demand might be even lower than that.[TEM 2009]

In the case of higher development of wind power and nuclear power and if the demand increases only little, self-sufficiency is possible and significantly improved

CF is also possible. As the target / plan for reducing greenhouse gas emissions compared to 1990 levels is 20% by 2020 and 80 / 95% by 2050, we can also assume that effective measures will be taken in use in order to improve the CF of electricity.

The newest prediction made by the Finnish Ministry of Employment and Economy is being done in the connection of the new climate and energy strategy that will be published during this year. On the basis of preliminary information[1] and in accordance to the newest base scenario the predicted emissions for district heat and electricity are as follows:

Table 16. Predicted emissions for district heat and electricity.

Characteristic emissions g CO_2/kWh	2010	2020	2030
electricity delivery	230	179	36
district heat	243	216	191

The base scenario takes into consideration the measures already decided such as feed tariff for electricity delivery, subsidies for renewable energy and nuclear power plants already received positive decisions in principle. The allocation of fuels in CHP district heat and electricity was done on the basis with energy method. The scenario also assumes that all electricity is produced in Finland in 2020 and 2030. The scenario considers the assumed decrease of energy demand for heating of buildings [Airaksinen, BAU scenario]). The BAU scenario takes into consideration the impact of energy performance regulations and the impact of changes in building stock (demolition of building and building of new buildings). In addition, the TEM scenario assumes that the use of heat pumps is increased so that those contribute to 7 TWh of the use of primary energy. It also assumes that oil heated houses change the heating system and make use of ground heat pumps and the houses heated by electricity use air heat pumps.

As there is a rapid change in the assessed values between the years 2010, 2020 and 2030, the possible consideration of this change in life cycle assessments of buildings has a significant effect on final results. It is here recommended that especially when making building specific life cycle assessments over 50 years' period, the assessed change in emission values should be considered. An example of the significance of the issue is given in the following:

> Chapter 6 presents assessment results about the significance of materials is renovation projects and in new building. Among other calculation examples a multi-storey building was assessed (see Tables 27 and 31). When the GHGs because of total operational energy use during 50 are calculated by using the emission values of 2010, the result is significantly bigger

1 preliminary information received from TEM 13.4.2012 (Bettina Lemström).

(1.99Mt CO_2e) than when the total GHGs are calculated considering the predicted change in the emission values of electricity and district heat (the assesses result falls to1.44 Mt CO_2e). Thus also the share of building materials' share from the total GHGs increases (in this example it increases from below 20% to roughly 25%). The share of materials in the latter case roughly equals to the combined share of heating and electricity while the heating of water is responsible for roughly 50% of the GHGs.

However, when making building stock based analyses about the significance of renovation scenarios, it is also important to take into account, whether a particular decrease in the demand for delivered electricity is actually needed as a partial measure in order to make the change (decrease of GHGs) to happen. The ability of building sector to react to the challenge is indeed an important prerequisite for Finland to be able to respond to the requirements of decreasing GHGs. The role of building sector is double in such a way that it is first important to decrease the GHGs of the building stock with help of improved energy performance and indirectly to enable the better power generation (in terms of GHGs) with help of reduced demand for delivered electricity.

Chapter 11 shows assessment results for the final energy use and related GHG emissions of the Finnish residential building stock in 2020 and 2030 (see Table 82 and 83). According to the results the total final energy demand in 2030 would be 29 TWh including 29 TWh for heating spaces and 9.2 TWh because of electricity use. This assessment takes into account the assessed outgoing share of the current stock and the share of building needing either light or thorough renovation during the coming years. It is also based on assumption that an effective combination of energy renovation measures would be done for those buildings that need thorough renovation. The share of electricity from the assessed 29 TWh is 27% (7.8 TWh). However, the total use of electricity could be further decreased by roughly 4 TWh with help of ground heat pumps of detached houses.[2]

Assessed demand for delivered energy of existing building stock in 2030 (copied from Chapter 11).

	Energy Heating TWh	Energy Electricity TWh
2030, no energy renovations	44	8.9
Renovation combination	29	9.2

[2] Note that this calculation uses the values of Table 16 which were not used in the calculations presented in Chapter 11. Chapter 11 uses the values of year 2008.

Assuming that the energy is produced with help of district heat and electricity and by using either 2010 values or 2030 predicted values for GHGs, we receive different results for the assessed impact of building stock in 2030. If we

– assume that an effective combination of renovations is done for all buildings that will require thorough renovation during coming years
– consider the effect of outgoing share of building stock but do not take into account new buildings between 2010 and 2030
– use the energy method for the allocation of emissions,

we receive the following results:

– the assessed GHGs of the existing building stock is 9.1 Mt by using the present values
– the assessed GHG of the existing building stock in 2030 is 4.7 by using the predicted values (2030)

If we further consider the assessed savings in demand for delivered electricity because of the change of attached houses from electrical heating to ground heat pumps, we receive the following results:

– the assessed GHGs of the existing building stock is 8.1 Mt by using the present values
– the assessed GHG of the existing building stock in 2030 is 4.5 by using the predicted values (2030).

4. Alternative energy renovation methods

This Chapter discusses four alternative energy renovation methods. The energy renovations presented here are as follows:

- additional thermal insulation
- window replacement and improved air-tightness
- renovation of the ventilation system and
- utilization of solar heat.

The building regulations regarding the thermal insulation of the building envelope has tightened significantly over time as the understanding about energy related threats has been improved and as the heat insulation materials and techniques have been developed. Structures filling current regulations would not have been possible with help of traditional materials and structures of the 1960's without massive and costly structures. On the other hand, by using current materials, filling the requirements of that era is much simpler and cheaper.

Even though the heat loss through the building envelope is significantly smaller in new buildings, renovating existing buildings only for energy-saving reasons is seldom profitable. The biggest advantage of energy renovations is achieved, when it takes place in the connection of other renovation activities. Examples of this kind of renovations are as follows: replacing badly damaged windows to modern windows, additional thermal insulation of the external wall when re-rendering the façade.

4.1 Additional thermal insulation of the building envelope

External walls usually form the biggest area of the building envelope, therefore having a big impact on the heat losses of a building. Additional thermal insulation of external walls can be made in a number of different ways. Two main categories, which are typically used in Finland are: additional external thermal insulation and additional internal thermal insulation. The so called cavity insulation – although commonly used in other parts of the Europe – is not used in Finland, because of un-insulated cavity walls have not been much used.

4.1.1 External thermal insulation

External thermal insulation is usually the simplest solution for additional thermal insulation of external walls. In this method the existing water vapour barrier can stay intact and the joints of external wall with internal walls and floor slabs need not to be concerned. However, it is important that the new external thermal insulation and the external cladding are not too tight considering water vapour penetration. This is important to avoid forming a dew point between the new insulation material and the existing wall, or behind the new external cladding. The dew point and the resulting condensation can be avoided by using mineral wool as thermal insulation material and leaving a ventilated air gap behind the new cladding.

Installing external thermal insulation is profitable in cases, where the external cladding needs to be replaced. A typical example of this kind of case is replacing the outer layer of concrete sandwich elements with external cladding or rendering. In these cases the external layers often need to be removed, so conditions for adding external thermal insulation are good.

Another typical case is renewing the rendering of a rendered brick or block wall. In these cases external thermal insulation is typically fixed on the existing structure with bonding and adhesives and the new rendering layer is added on top of the new thermal insulation layer. A steel reinforcement is often fixed on top of the thermal insulation layer to prevent the new rendering from cracking. An alternative solution is to clad the external wall with panels.

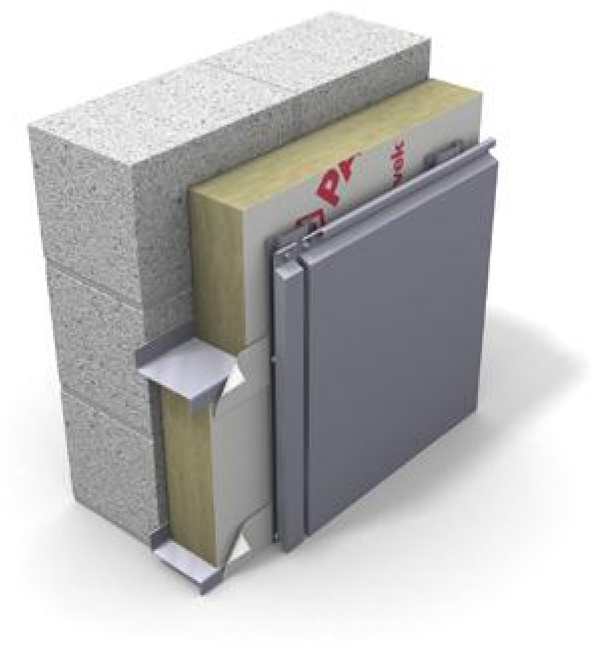


Figure 11. Rendered massive brick or block wall, with additional thermal insulation and panel cladding.

Wood-framed walls or wood-cladded logwood walls can also be externally insulated. In these wall types, the existing cladding is first removed and a new thermal insulation layer is installed on top of the existing wood-frame or logwood wall. This fixing can be done either by wooden battens or with mechanical fixings. The surface of the additional insulation is then followed by installation of wind screen (if necessary), ventilation gap and external cladding. If the existing structure includes a wind screen, it can be left in place and apply the additional thermal insulation on top of that. One alternative for the wooden cladding is to finish the structure with a rendering, as in the following image.

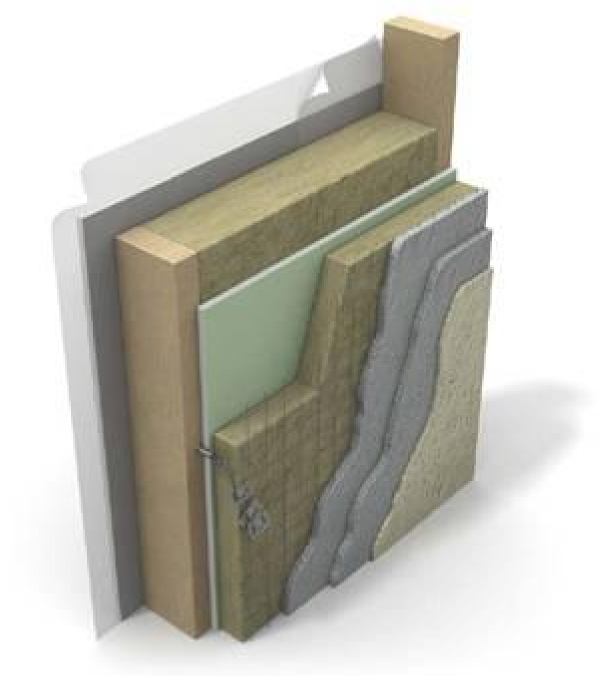


Figure 12. Wood-framed wall with additional thermal insulation and three-layer rendering.

Since 1960's the residential blocks of flats in Finland have been mainly built using concrete sandwich elements. The most reasonable refurbishment method in technical-economical terms is defined by the condition of the outer concrete layer. If the outer concrete layer is in a bad condition, then the best solution is to demolish the outer layer, remove the existing insulation and install new external insulation. This kind of thorough renovation allows the new thermal insulation layer to be passive-house-level, if other technical aspects don't prevent this. It should also be noted that when renovating walls to passive level, the ventilation system of the building should also be renovated for the renovations to be effective. The additional thermal insulation is usually mineral wool and it can be up to 300–350 mm thick. If hard mineral wool is used, a supporting frame for the thermal insulation is not needed. These kinds of structures are usually finished with a rendering. If a massive cladding, such as brick wall, is used, then new foundations for the external wall structures are needed.

If the outer layer of the concrete sandwich element is in good condition, demolition of the outer layer is not cost-effective. The renovation procedure of such a concrete element is that the outer concrete layer is first bolted to the internal concrete layer, insulation is then added and the structure is finished, for example, with a rendering. In this kind of renovations the insulating material can also be polystyrene or polyurethane based. The thickness of the additional polystyrene insulation layer is typically 50 to 100 mm. In theory, the heat insulation properties of the wall can be doubled, but in practice the improvements can stay at 50% on average. This can be caused by poor details in refurbishments, such as not renovated window and door connections, and not insulated window and door embrasures, which cause thermal bridges. The effect of external wall insulation depends on the wall-window ratio. This renovation method has been in use for a long time and the techniques are well tested. The final result does not typically suffer from any cracking of the rendering.

The mineral wool insulation offers typically thermal conductivity from 0.031 to 0.044 (W/mK), polystyrene insulations from 0.028 to 0.045 and polyurethane from 0.023 to 0.029.

MECOREN project made calculations about the building physical behaviour of external walls with additional external heat insulation. The calculations were done with help of WUFI software. The preliminary results indicated that the risk for mould growth is usually lower in the additionally insulated structure than in the original structure. However, if some part of the driving rain penetrates into the structure through leakages there is some indication of increased risk for mould growth when impermeable insulation material is used. Further studies are being done in Korma research project and the results will be published later this year (2012).

4.1.2 Internal thermal insulation

Internal thermal insulation might be feasible, if the inner surface of the walls is in need of renovation. Internal thermal insulation usually requires installing water vapour barrier under the new inner wall sheeting. The water vapour barrier can be left out of the structure only when thin insulation layers are used. An example of this kind of case is installing a 12–25 mm thick wood fibre sheet on top of so called sawdust wall, or on top of logwood wall. On the other hand, the old water vapour insulation usually needs to be removed, to avoid forming a dew point inside the structure. The following figure illustrates internal thermal insulation of a logwood wall.

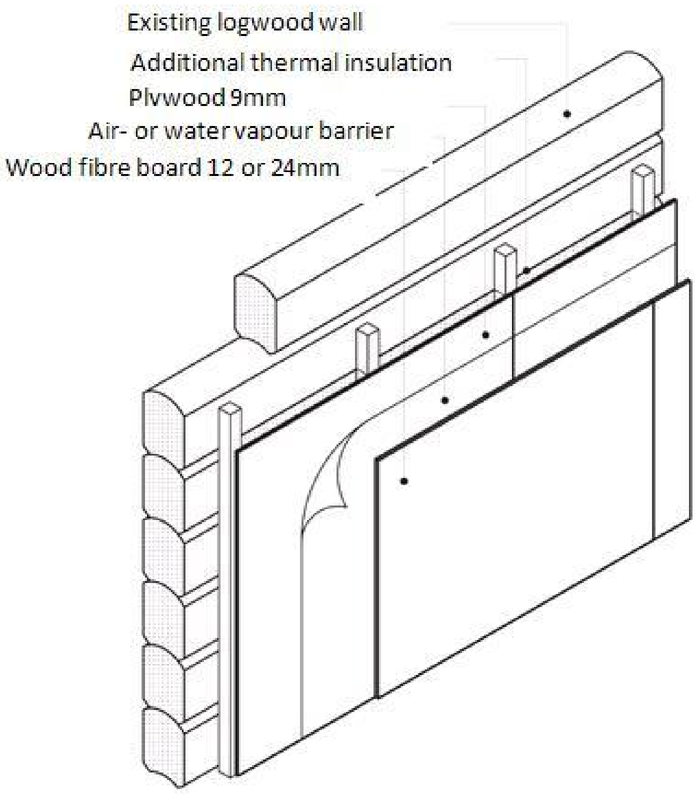


Figure 13. Additional thermal insulation of a logwood wall. Internal thermal insulation with mineral wool.

The so called plasterboard laminates are products, where the insulating material is laminated together with a gypsum board. These products can reduce the amount of installation work, since the insulation and gypsum board can be installed together. The seams between the insulation plates are sealed with polyurethane foam, as well as the connections to the existing walls.

4.1.3 Replacement of the insulation material

Replacement of the insulation material is a special renovation method, which may be necessary for example for sawdust walls. In this renovation method the sawdust is replaced with cellulose wool or mineral wool. The benefits of this method are based on the fact that the thermal conductivity of sawdust insulation is roughly twice as much as for mineral wool. The replacement should be made from that side of the wall (internal or external), which is in need of refurbishment. If the case is that internal wall surface needs renovation, then the old wall sheeting should be removed and the sawdust removed from the inside. If mineral wool is used for insulation, the renovation can be done from internal side only, since a water vapour barrier needs to be installed between insulation and wall sheeting.

The European SUSREF project developed and assessed refurbishment concepts for exterior walls. Concepts and assessment results are introduced on the web page of the project [SusRef].

4.1.4 Additional thermal insulation of roofs

Additional thermal insulation of roofs is generally easy in buildings with an attic. The safest way of renovation is to use the same insulation material, which was originally used, though sawdust-insulated structures should be insulated with cellulose wool. The insulation can be installed by blowing insulation wool onto existing surfaces, or for mineral wool, by installing insulation as sheets. The thickness of additional insulation is limited by the height of the attic and by the openings for the air cavities of the roof eaves. The following figure shows a simplified example of additional thermal insulation.

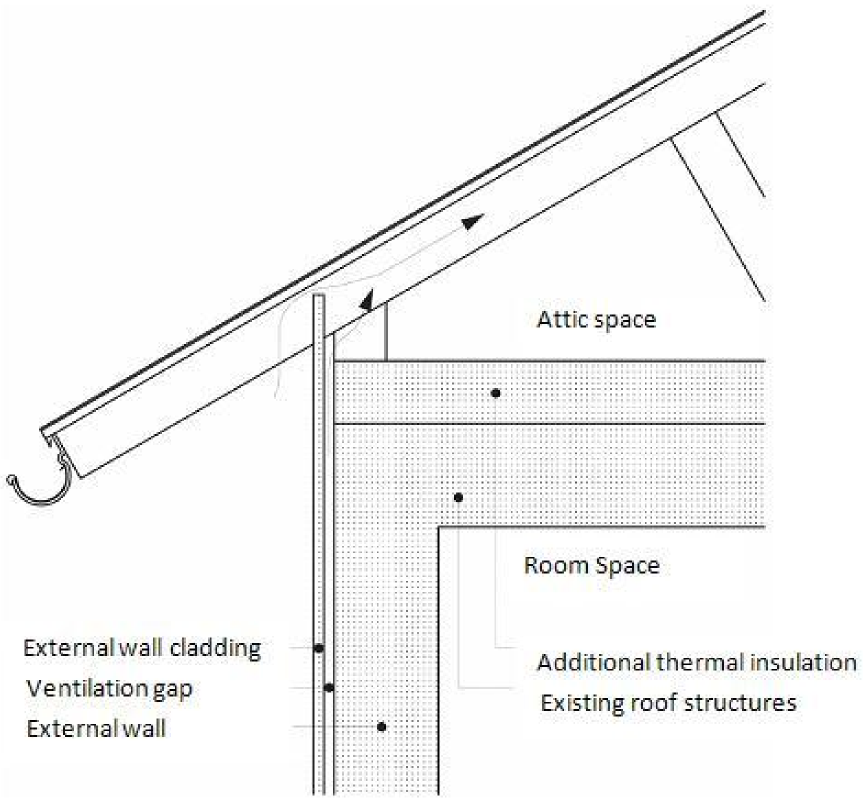


Figure 14. Additional thermal insulation of roofs.

Additional thermal insulation is viable for flat-roofed buildings only when the waterproofing of the roof needs to be replaced. In these cases the additional insulation can be made either by adding insulation thickness, or switching the insulation material from mineral wool or polystyrene insulation to more effective polyurethane insulation.

Another option is to add insulation on top of the existing waterproofing. The insulation should be made with mineral wool with ventilation channels. The upper layer of the structure should be made with a layer of roof insulation wool and covered with bitumen water proofing sheets.

4.1.5 Additional thermal insulation of the base floor

The role of the base floor in heat losses of a building is less than 10%. Due to this, only relatively small improvements on building-scale energy efficiency can be achieved by additional thermal insulation of base floor.

Additional thermal insulation of base floor can be done either by adding layers of insulation material on top of the existing floor, or by replacing the existing insulation material with a more effective insulation. Adding insulation on top of the existing structure is often not possible, since this method raises the floor level, causing, for example, problems with doors.

The following figure presents how a heat insulation material + slab structure can be used as internal additional heat insulation.

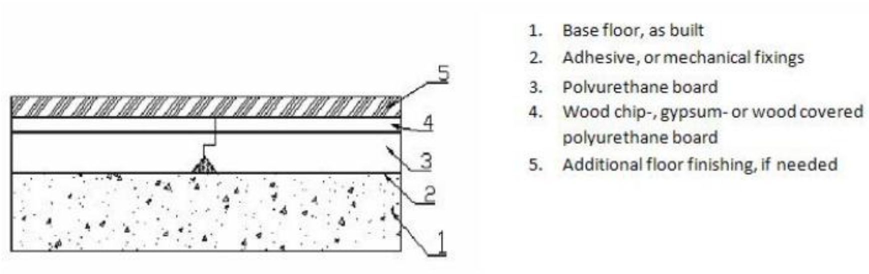


Figure 15. Additional thermal insulation of base floor with polyurethane boards.

Adding insulation thickness to the insulation of foundation wall or frost insulation also diminishes the heat losses through the base floor. It also reduces the risk of frost damages for a building. The following figure illustrates two different ways of adding frost insulation. One with horizontal thermal insulation boards (the left side of the image) and one with vertical thermal insulation boards (right side of the image).

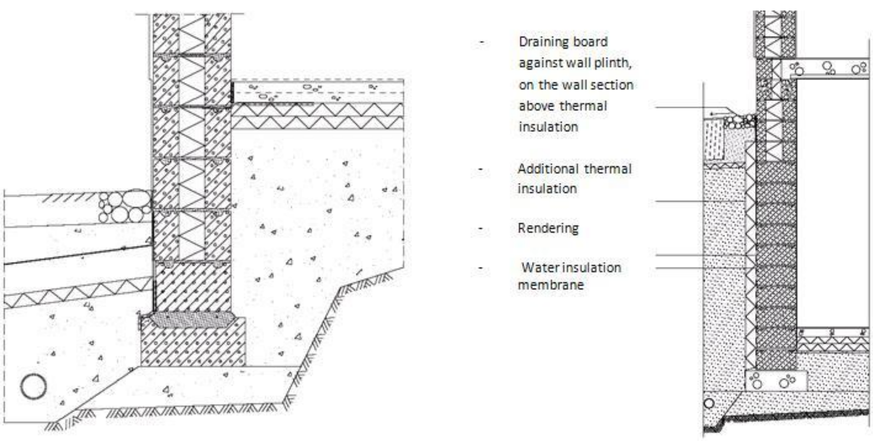


Figure 16. Additional thermal insulation for frost improves thermal insulation of bottom floor slab.

Replacing the heat insulation material of the base slab with a different material (usually replacing sawdust with mineral wool) is usually profitable if the floor surface needs to be replaced. The replacement of the insulation material diminishes the heat losses since sawdust's thermal conductivity is twice as much as that of mineral wool.

4.2 Window replacement and improvements in air-tightness

The windows represent about 10–15% of the total area of external walls. Even though the window area is relatively small, the heat losses through windows can be of the same order of magnitude as that of external walls. The reason for this is that the thermal conductivity of windows is significantly higher than that of walls.

The glass technology has undergone significant development in the last decade and it has created possibilities to bring the insulation properties of windows to a new level. The heat insulation is best improved by replacing the windows. However, also installing an additional front glass or insulation glass to complement the existing window frame, or completely replacing the window glasses with new ones, may be beneficial. However, the energy saving benefits of window replacements are relatively small, so it is not usually profitable to renovate windows only because of energy-saving reasons.

The most energy-efficient windows may have frost in their outer side in August and September, when the sky is clear. This causes problems in aesthetic appearance and usability, but is not a concern regarding long-term durability.

4.3 Increasing the air tightness of the building envelope

Increasing the air-tightness of the building envelope reduces unwanted air infiltration and energy-losses. Air leaks can be caused by gaps in joints between building components, due to holes in structures for building services installations and lack of insulation. The air-tightness of a building is defined with air-leak-factor which is measured with a 50 Pa pressure difference. It amounts typically to 2 to 4 exchanges per hour (number of times the air inside the building changes in an hour). Tightly sealed houses have less than one exchange per hour and unsound ones have over five changes per hour.

The easiest and most economical way of sealing a house is replacing the sealings of windows and doors. This may lead to significant savings, if the old sealings are in bad condition. Another easy measure is to seal the joints between windows or doors and the external walls.

The holes for ventilation, water and waste water channels, as well as electrical installations, must be sealed and air tight. In many cases they can be sealed during renovations. However, if water vapour barrier has unsealed holes for such installations, the repair is generally impossible without opening the structures. Some deficiencies in water vapour barrier can be fixed with installing a new water vapour barrier during installation on internal thermal insulation.

The seams between existing structures can be usually improved, for example, with polyurethane foam. An example of this kind of procedure is re-sealing of the joints between load-bearing concrete structures of a building and a light, wood-framed balcony wall.

When a building is renovated in a way, where the external facade layers are removed, the visible seams can be re-sealed. This improvement is based on increased air-tightness of the internal envelope. Adding external thermal insulation, such as polyurethane, on top of existing structures does not increase the air tightness of the envelope in a significant way.

The simple replacement of windows and doors can also increase the air-tightness of a building envelope. This is due to the fact that usually about half of the seams of a building are related to windows and doors.

Parts of the building, in need of air-tightness renovations can be studied, when the outside temperature is less than -5 ^{o}C. The points of unwanted air passage of a building can be pointed out with thermal imaging, when an under-pressure is introduced inside the building.

4.4 Renovation of ventilation system

A well-functioning ventilation system takes part in providing the building with high-quality air and taking care of the condition of building structures. The ventilation system must be able to remove the impurities which are produced to the inside air (smells, moisture, carbon dioxide) and inorganic compounds evaporating from the interior materials.

Natural ventilation is driven by the so called thermal pressure-difference, which is caused by density differences between internal and external air, and pressure-difference caused by wind. Mechanical exhaust ventilation produces under-pressure inside ventilation channels.

In mechanical supply-exhaust ventilation systems, both the supply and exhaust air are brought inside the ventilation channels into and out from the building. These systems are usually equipped with heat recovery system, which warms the supply air by collecting heat from the exhaust air. A well-functioning system makes additional ventilation by opening fresh-air windows needless.

Energy-efficiency improving ventilation renovations always need a feasibility study, and their installation should not lower the quality of the indoor air. Energy renovation activities can also affect only parts of the ventilation system, but the analyses must consider the resulting consequences on other building components, such as electric and structural systems.

Upgrading natural ventilation system to mechanical ventilation, centralized solution

Upgrading natural ventilation system into supply-exhaust mechanical ventilation is equivalent to installing a completely new ventilation system. In such a large-scale renovation, the current building regulations concerning the amount of air-flow and air-tightness need to be followed. The demolition and installation work is responsible for a large share of the total cost of this kind of renovation. Usually completely new ventilation channels need to be built, even though the new channels can be installed inside the existing exhaust air channels.

Since buildings need to be under-pressurised, the supply air flow of a mechanical ventilation system is set to be 10–30% smaller than the exhaust air flow. When a fully mechanical ventilation system is installed, structures, which are not air-tight, can cause draft and waste of heating energy. The less tight the building, the smaller the amount of supply-air must be to avoid the negative impacts of wind on ventilation, such as air-flow through external walls. The openings in structures which are needed for installation of the system may further lessen the air-tightness of a building.

In residential blocks of flats the ventilation unit and the heat recovery unit can be placed in the attic space. The new exhaust air channels are installed inside the existing exhaust-air channels. The supply air can be blown into the staircase of the building (so called pressurizing of the staircase) or through new supply air channels directly into the apartments. If the supply air is delivered directly into the apartment, the resident can adjust the amount of air flow with. The system can also use efficiency-enhancing air-vents.

Installing plate heat exchanger requires that the supply and exhaust air units are placed inside the same space. If the units are placed in separate spaces, or in case of decentralized ventilation systems, water-glycol-system is better suited. Plate heat exchangers typical dry heat efficiency rate for supply air is 50–60%, for water-glycol-systems 40-50% and for rotating heat exchanger 60–70%. The condensation improves the efficiency rate of heat recovery.

Apartment specific ventilation system

One option for the ventilation system of residential blocks of flats is a distributed mechanical supply-exhaust-air ventilation system. In this system all of the apartments are equipped with their own, separate ventilation system. This system is particularly applicable, if requirements for indoor air and energy-efficiency are especially high. The ventilation unit can be placed, for example, in kitchen, in bathroom, or in walk-in clothes closet. The supply air is channelled in through the building wall. Apartment-specific ventilation unit's supply and exhaust air needs to be adjusted to be equal. If the exhaust air flow exceeds the supply air flow, a risk of backflow from the existing natural ventilation channels exists. Room-specific systems' air supply from the wall is not allowed in all the municipalities in Finland.

Implementation of a ventilation system with heat recovery is easier in the centralised system with a single ventilation unit. In the case of distributed systems, it is advisable to consider combining some of the units. The price of the ventilation units is lower in the centralized system, but costs of installation of the ventilation channels are high.

In addition to the centralized and distributed solutions, also another solution exists. One way of implementing ventilation renovation is to add heat-recovery to the existing exhaust air-system and to distribute the recovered heat by water circulation heating system.

According to the Finnish Real Estate Federation, no renovations where the ventilation system is upgraded from natural to mechanical ventilation, has occurred in the Finnish stock of residential blocks of flats. Price-estimates and evaluations of suitable solutions can be found from the deliverables of research project KIMULI (Keijo Kovanen). This research studies both distributed and centralized solutions.

4.5 Heating systems

Energy sources (district heating, renewable energy sources and systems, decentralised systems) and heat distribution

The heat production system is a crucial part of the heating system of a building. Heating systems include such systems as:

- heat exchanger for district heating
- boilers using light fuel oil
- boilers using heavy fuel oil
- boilers using wood pellets, peat or wood chips

Renovation of the heating systems means refurbishing or renewing the heating system of a building, when it is at the end of its technical life cycle. On the other hand, heating system renovation may also mean changing the whole system to a more energy-efficient system. In this case, the system components might still have some technical lifetime left.

The selection of a heat production system is made by the circumstances, which exist at the time of the construction of a certain building. These circumstances may change, for example, when district heating network expands, or when technical changes are made to the building. The main principle is that the selected heating system is maintained for its whole lifetime. When this lifetime closes to its end, alterations for the system are considered. The renovation and alterations of heating systems are technically relatively large operations and always require economical feasibility studies.

When planning a renovation for a heating system, the following aspects need to be taken into account:

1. The condition of the heating system at the moment of control
   - losses of heat production
   - remaining technical lifetime
   - the technical condition and remaining lifetime of other heating system components.

2. The price development for the planned fuel in the future.
3. The environmental effects of the planned fuel (such as particle and CO_2-emissions).
4. Filling the requirements due to the heating system refurbishment (such as changed heating power need, need of technical space).
5. The effects of the heating system to the maintenance process (need of inspections and maintenance).

Connecting a building to regional or district heating

The district heating has a smaller environmental impact than building-specific heating plants. Connecting a building to district heating depends on the cost of the connection and on the condition of the heating system of a building. The connection is not nearly always possible, since it depends heavily on the location of the district heating network.

If connecting building to a district heating is possible, the feasibility should be evaluated, based on life cycle calculations. A generally used refurbishment method, where the old heating system is left in place, to save costs, is not advisable. If the old heating system is removed instead, it is possible to gain additional storage space to a building, and to remove health risks (such as asbestos insulations) related to the system.

Renovating distributed heating system, or a water-circulated electrical heating system into centralized geothermal heat pump system

Geothermal heat pump systems use the heat of the ground. The heat is extracted, for example, by horizontal piping, installed to one meter depth, from a vertical hole drilled into a solid rock, or from the bottom of a lake. The heat is transferred by piping, with the help of a circulating heat transferring fluid, into a heat pump. The most effective way of heat distribution is floor heating, due to the fact that its operating temperatures are lower than with radiator systems.

Complementing room-specific electrical heating with an air heat pump

The heat pump allows the outside heat to be used for heating the spaces. Experiences of air heat pumps in Finland are only short-term, and mainly from detached houses. Their use is restricted by the strong variation decrease of the thermal coefficient, when outside temperature drops. Therefore the air heat pump cannot be used as a primary heat source, but only as a complementary system. The installation of air heat pump system requires a re-design of the heating system, which enables its right sizing. The installation of such a system is subject to licence in Finland.

Converting heating system into a wood pellet powered boiler system

Some of the properties of pellet heating require specific attention in the design. The pellet system needs constant observation and the storing of the fuel needs specific attention. The pellet storage needs to be placed in a dry space so that the transfer to the burner does not cause problems. If the storage space is located outside of the building, it needs to be heat insulated, or some other protecting means needs to be applied to keep the fuel from getting moist. So far no research data is available on the functionality of pellet heating systems in refurbishment of buildings in Finland.

Attaching solar heat into water-circulated oil or electric heating system

In solar heating systems, the solar radiation heats the heat transferring fluid in the solar collectors. The heat transferring fluid delivers the collected heat into the water of a heat storage tank or a boiler. The circulator of the collector circuit starts only when the temperature is sufficiently higher than the temperature in the heat storage and stops when the temperature in the storage is adequate.

The solar collectors are oriented between south and south-west. The collectors are easiest to install on a tilted roof, but with the help of supporting frames they can be installed to a right angle even on a flat roof. The number of collectors is usually between 2 and 5, while the total area of collectors is between 5 to 12.5 m^2 (the area of a single collector is about 2.5 m^2). The size of a storage tank in solar heating system is between 300 and 1000 litres. An oil boiler can also be used as a storage tank for solar heating system, if the size of the water storage is expanded.

The heat from solar collectors is used for heat hot water production or for heating of spaces. The system components include solar collectors on roof, the distribution circuit (including the pipes and the circulator), and a storage tank (or a boiler-integrated storage). System components which need to be added to the existing system include solar-oil boiler, solar heat storage tank and a new oil burner.

When renovation is planned, all relevant heat production systems should be considered. The EcoDrive research project studies the replacement of electric heating system with district heating system and utilization of solar and ground heat.

The heat distribution considerations should include air heating systems, where the temperature of the supply air is in the range of 20 to 50 degrees Celsius. It is a reasonable method, when the heat losses of a building are relatively small [Saari 2004].

Reducing the energy consumption of a ventilation system by control systems and maintenance

The basic adjustments and maintenance of a ventilation system means ensuring that the system components are functioning at their design values. The actions may include repairs requiring investments, or improvements in the use, which can be achieved with existing system components. Renovations of ventilation systems involve removing and replacing unfit system components, repairing and refurbishing parts in need of maintenance, improving quality standards and removing detected problems.

The draft-related problems are typically caused by inadequate air tightness of windows and unsatisfactory design of the air distribution. The effect of poor windows cannot be usually compensated with ventilation system repairs, and, in any case, it is not feasible from the point of energy-efficiency. When the air flow rates are increased due to the basic adjustments, the energy consumption of the system rises. The following, component-based study focuses only on the actions which can lower the energy consumption.

Fan

The energy use of a fan can be lowered by shortening the usage time, controlling the air flow amounts, according to actual use, by decreasing the resistance of the ventilation channels and by improving the overall efficiency of the fan. Factors lowering the efficiency of a fan are: disturbances in the air intake (causing turbulence in the air flow), over-sized electric motor, too loose or tight belt, dirtiness and insufficient channel joints. The operating point of the fan should be in the area of the best efficiency. A frequency converter can be installed to an existing system with minor effort, in most of the cases. The control of the frequency converter can be based both on air quality and temperature.

Guide-vane control device is used when the fan has wings which are bent backwards. It is economical with high air flow volumes and pressures. In ventilation units, where the average air flow volume is small, compared to the maximum volume, the guide vane can be supplemented with two-speed control. Wing-angle control device is a low-cost alternative in big ventilation units, whose air flow variations are big. When using two-speed fans, the speed is decreased, for example, when outside temperature falls below a certain level (such as -15 degrees Celsius).

External grill

An external grill of an energy-efficient ventilation system should be below 40 Pa. The pressure losses are increased by rust, clogging of the grill, loose fixings, freezing, and inadequate separation of water and snow.

Dampers

The most important properties of an energy-efficient damper are tightness and coefficient of heat transmittance. The seams of the damper need to be in good condition and the damper should be located as close to the external grill as possible. The damper for external air should be fully able to open so that unnecessary pressure losses are avoided. The incomplete closure of roof exhaust fans causes needless heating energy consumption.

Filter

If the replacement period for the filter is too sparse, its pressure losses, as well as fan's electric consumption are increased. An incorrect installation causes pressure losses and shortens the replacement period. Each of the filter types are designed for a specific air speed ranges, within which, their functioning is efficient.

Heating and cooling radiators

The pressure loss of a radiator is affected by the face velocity and contamination. If the face velocity is above 3 m per second, a drop separator should be used.

Heat recovery unit

The efficiency of a heat recovery unit is lowered by air by-pass, contamination, too small flow rate of the heat transfer fluid and malfunctions in control. A frozen heat recovery unit lowers the amount of exhaust air flow and increases heat resistance, so that the recovered heat and the air change are lower. On the other hand, an anti-freeze control, which works needlessly, results in a lower efficiency and also lowers the amount of recovered heat. Freezing can be prevented by pre-heating the supply air, or by lowering the power of the heat exchanger, either by adjusting the speed of rotation, or by air by-pass rate.

Air ducts

Unnecessary pressure losses in the ventilation channels are caused by abrupt corners, without guide vanes, in rectangular air ducts, duct branches without collars, and too small openings in duct branches with collars. If some of the duct branches have a significantly lower pressure loss than others, it can be more beneficial to enlarge that specific duct, than to maintain a higher pressure level inside the ducts due to that.

Control and monitoring devices

Unsuitable operation settings, and false responses on disturbances by the control circuit cause problems in the operation of the system and may result in unnecessary use of energy.

Initial adjustment of heating network

The initial adjustment of heating network aims in setting the temperatures of the different spaces of a building as close as possible to the designed base values for internal temperature. The base value during heating season is often between 21 and 23 degrees Celsius. A prerequisite for a successful initial adjustment requires that line valves are in good condition, when the water flow rates can be adjusted. In many cases, most or all of the radiator valves are replaced during the initial adjustment of a heating network.

The initial adjustment needs to be done always, when the heating energy demand of a building changes, in example, due to change of space, additional insulation or window replacements. The profitability of the measure is usually excellent.

The frequency converter control of the pumps of the heating network lowers the electricity consumption of the pumps. This measure is also usually highly profitable, and should be done when pipes of the heating network and circulation pump are replaced.

The savings potential of automatics and control systems on a general level – and when taking necessary air flows into consideration – may be significant. Technical information is available in the final report of INSERT-project (Satu Paiho).

5. Methods for additional thermal insulation

5.1 Additional thermal insulation methods for structures

Additional thermal insulation is more effective, safe and cost-efficient, when applied on the external side of the structures. When applied on the internal side, some discontinuity points are inevitably left in the thermal insulation. For example, the connections of external wall and internal walls, or floor slabs, act as thermal bridges after renovation.

The structures outside of the thermal insulation operate in lower temperature, than originally, leading to an increased risk of moisture damage. This risk is further enhanced by construction errors, and defects in thermal insulation and air-tightness.

When internal thermal insulation is applied, a new water vapour- or air-barrier layer is usually installed. The installation of such barrier is often labour consuming and requires careful planning, especially at the discontinuity points of the structures.

External thermal insulation rises the temperatures inside the original structures and, in general, usually creates better prerequisites for proper functioning of structures. The major risks in external thermal insulation are related to the rain water penetrating the structures from external side, due to improper or faulty structural details. Typical risky points in structures include the weathering of doors and windows, and edging strips at eaves.

If the external thermal insulation materials have low water vapour permeability, and water penetrates in the structure, entering the boundary surface between the new insulation and existing material, risk of moisture damage exists. The drying of water is extremely slow, increasing the risk of moisture damage. This problem highlights the importance of careful and detailed design and high-quality installation work of rainproof structures.

Theoretically assessed, structures with additional thermal insulation can be made with water vapour barrier at the external side of the structure, if the thermal resistance of the new, insulated structure is more than quadruple, compared to the original one. The structures with additional thermal insulation have a lower drying potential, compared to original structures, making the waterproofing extremely important. Usually structures with proper moisture-technical planning dry quite fast, when the weather conditions are suitable for drying. For example, even moisture-technically faulty wooden structures which get damp during the winter-season, will dry to acceptable level in 1…2 weeks' time, when increased sunlight and over 0 °C temperatures in the spring season begin.

Structures with ventilation gaps are safer, than those without. If the external thermal insulation has leakage points where the rainwater can penetrate the external cladding, the penetrated water tends to flow downwards along the internal side of the external cladding. The air in the ventilation gap is able to dry slight leakages, preventing damages for the structure. In the unventilated structures, the penetrated rainwater immediately reaches the thermal insulation of a structure, making it moist. The drying after this will depend essentially on the water vapour permeability of the external cladding, and on the temperature distribution in the structure.

The thicknesses of additional thermal insulations do not have absolute technical limitations. However, the limitations are often set with financial constraints. However, it should be noted that increased thermal insulation lowers the temperatures of structures, decreasing the drying potential of them.

The additional thermal heat insulation methods of typical concrete-sandwich elements have some things to improve. In a typical renovation, a thermal insulation slab is installed on top of existing wall, and then covered with a cladding. With this method, the connections of the original element and windows and doors, will stay directly connected with the external climate. This causes the density of the heat flow rate to be higher at the edges of the insulated area, leading to a lower effectiveness of the insulation, compared to calculated values. More effective utilization of additional thermal insulation would require new solutions in window structures, or the details of thermal insulation.

The existing wall structures can be renovated to so-called passive level with additional thermal insulation. However, the insulation of sandwich elements will usually require demolition of the existing external wall structures, leaving only internal load bearing panel of the wall intact. The thicknesses of two-layered sandwich-structures are great, and additional thermal insulation would make them unreasonably thick. The renovations to passive level will usually require, from architectural reasons, moving the windows towards the outer surface of the wall, and extending the roof eaves. From economical point of view, the renovations to passive level require the existing wall structures to be in such a bad condition that its renovation is not possible or reasonable. Once the external layers are removed, the renovation is almost comparable to new construction and the structure can be made to match the so called passive level.

5.2 Common wall structures and their renovation methods

5.2.1 Insulated brick wall and reinforced concrete wall with brick-lining

Both, load-bearing and non-load bearing brick or concrete walls with brick-lining can be renovated with similar methods. The structural details are shown in the following figures.

Brick-lined, insulated brick or reinforced concrete walls can be usually insulated from the outside. In this case, the ventilation gaps in the original structures need to be closed, so that the maximum potential of the additional insulation can be obtained. The cladding of additional insulation can be selected freely. However, choosing brick-lining will lead to thick structures, and require widening the foundation structures of a building. If the cladding and existing insulation is removed (due to poor condition) the structure can be renovated to passive level. This case, too, requires widening the foundations, if brick-cladding is selected as the façade material. There are also benefits in altering the foundations, since the heat insulation of the foundations can also be improved while they are altered. If additional insulation is covered with a thin cladding material, widening of the foundations is often not necessary. However, it may be needed for architectural and aesthetical reasons. An important aspect in this type of renovation is to thoroughly investigate and design the insulation at the connections of windows and doors.

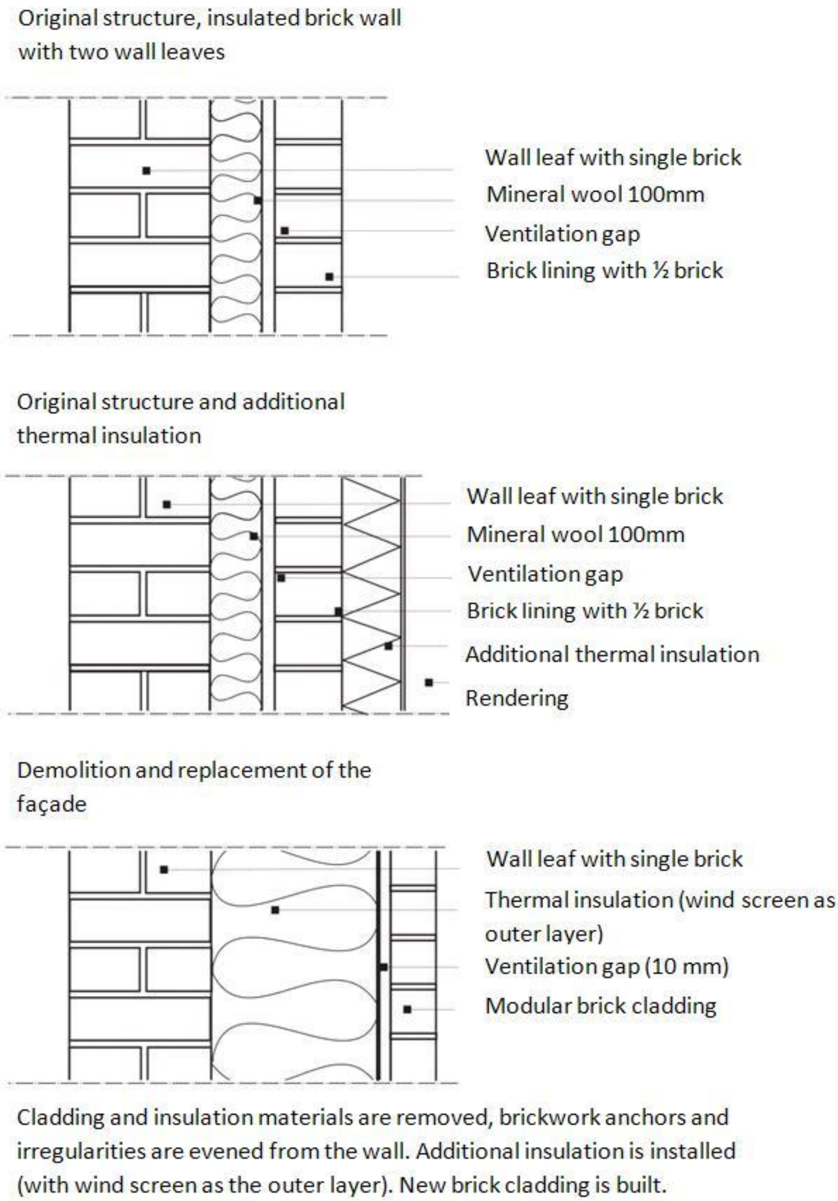


Figure 17. Brick-lined, insulated brick wall. Original structure and renovation alternatives with additional thermal insulation and replacing renovation.

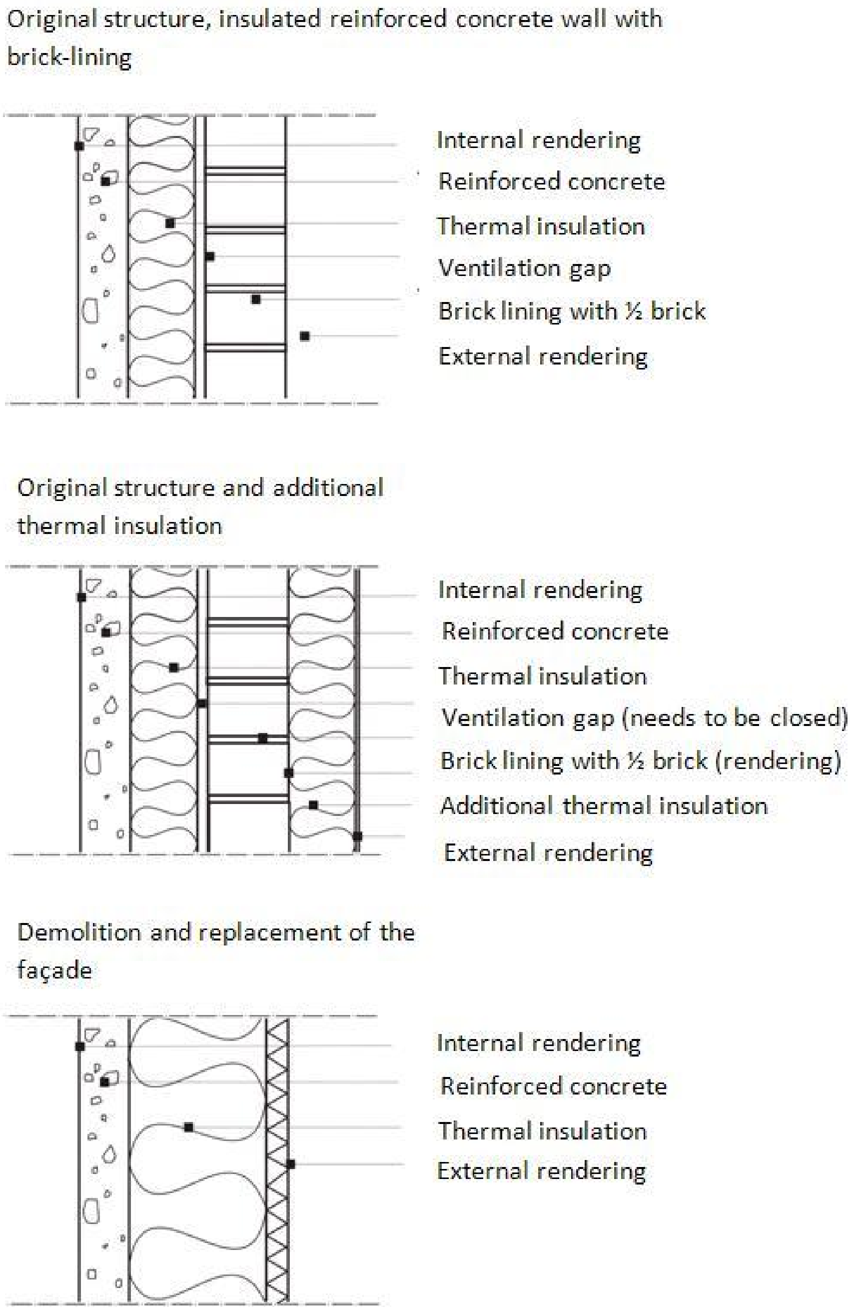


Figure 18. Brick lined, insulated reinforced concrete wall. Original structure and renovation alternatives with additional thermal insulation and replacing renovation.

5.2.2 Reinforced concrete wall with building board façades

Both, the load-bearing and non-load-bearing reinforced concrete walls with building board façades can be renovated with similar methods.

The renovations of reinforced concrete walls with building board façades usually include removal of the external layers, and are therefore, practically the same as building a completely new façade. If the support structure of the existing thermal insulation is in a good condition, it can be preserved, or removed, as wanted. If the new façade is clad with construction boards, it is advisable to build the façade as a ventilated structure.

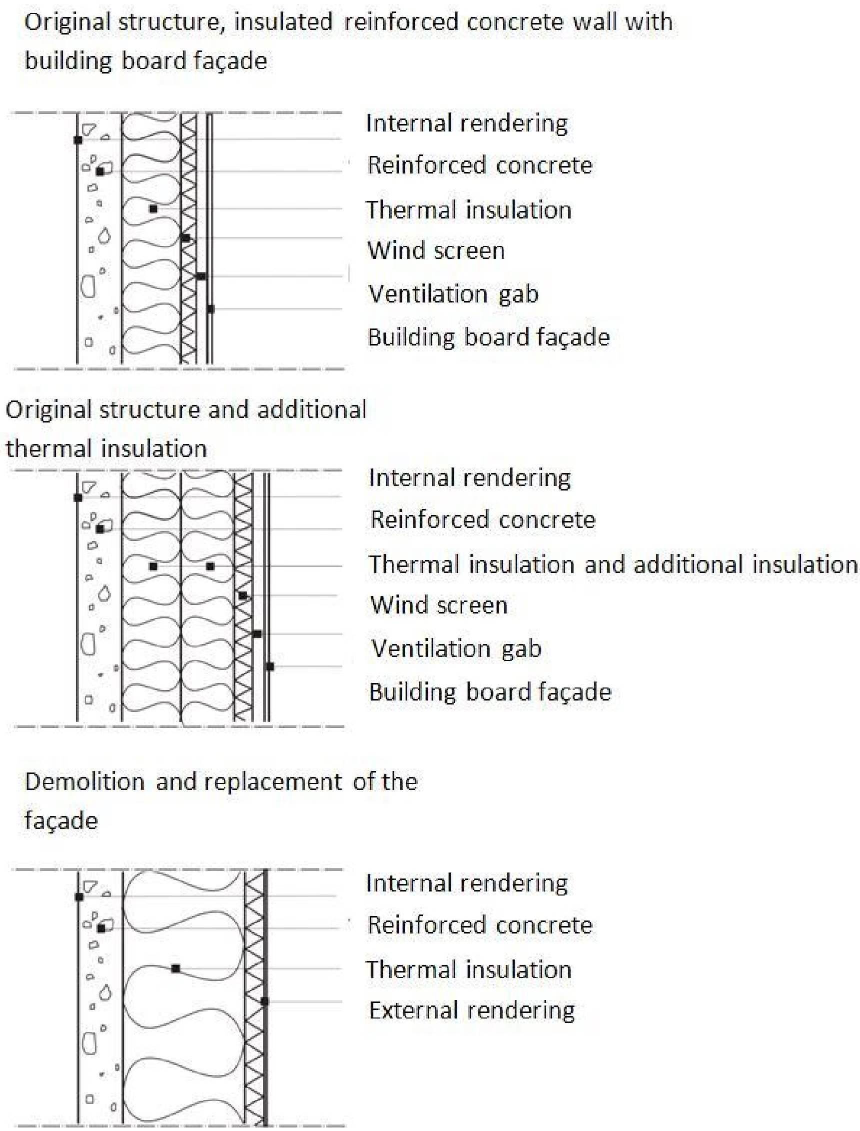


Figure 19. Insulated reinforced concrete wall with building board façade. Original structure and renovation alternatives with additional thermal insulation and replacing renovation.

5.2.3 Reinforced concrete wall with external light-weight concrete insulation

External thermal insulation of a wall with light concrete insulation is practically the only feasible solution for improving the thermal resistance of the structure. The external insulation is installed in a similar way, as in the previously presented wall types. The façade materials can be freely selected; however, brick-lined façade is not a common cladding solution, due to structural thickness of the wall

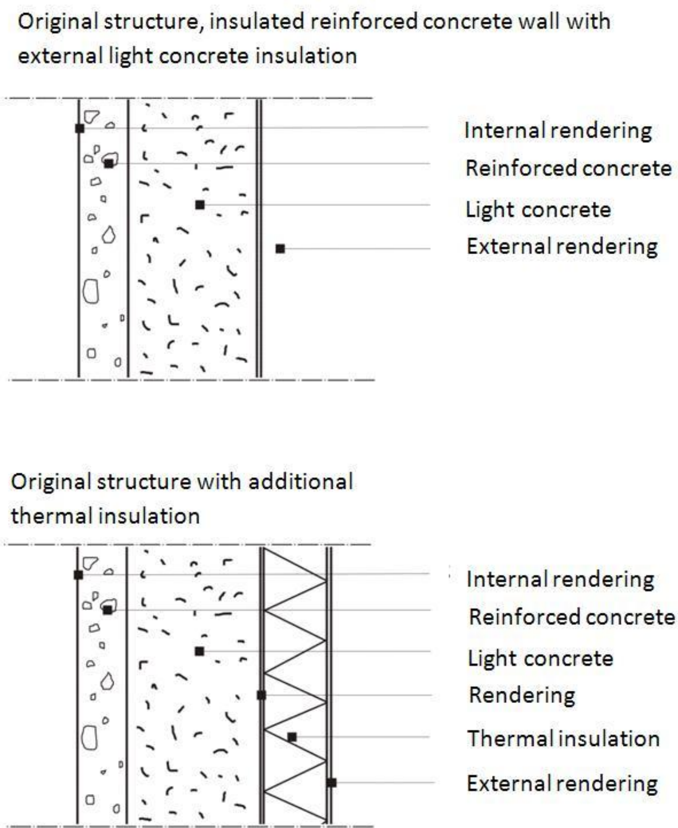


Figure 20. Reinforced concrete wall with external light concrete insulation. Original structure and renovation with additional thermal insulation.

The renovation solutions for a light-weight concrete wall with external and internal rendering are similar to the ones for reinforced concrete wall with external light-weight concrete insulation.

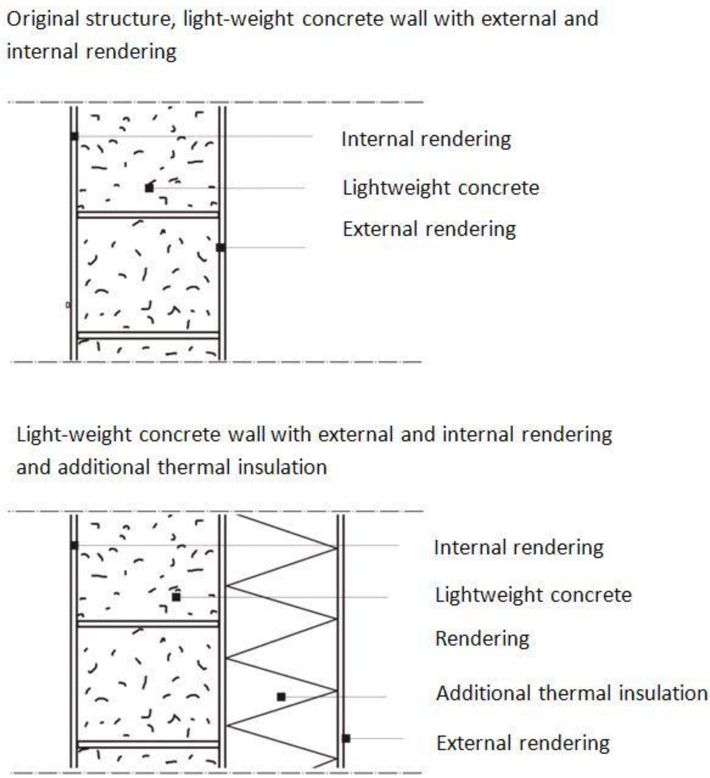


Figure 21. Light-weight concrete wall. Original structure and renovation with additional thermal insulation.

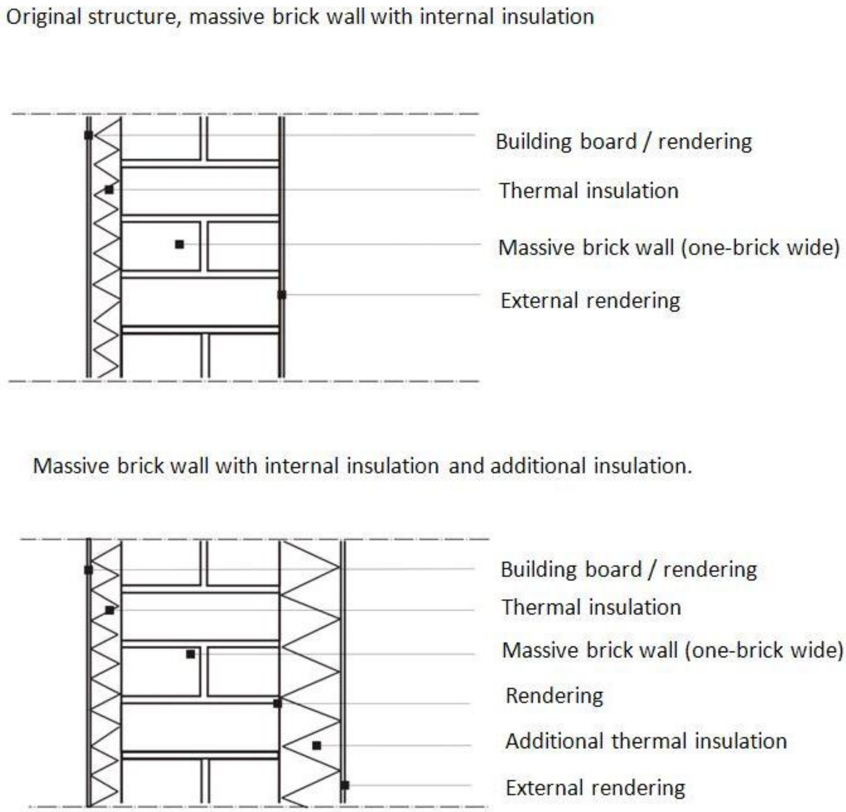


Figure 22. Massive brick wall with internal insulation. Original structure and renovation with additional thermal insulation.

5.2.4 Massive brick wall with internal thermal insulation

Internally insulated 1-brick brick walls are load-bearing structures. They are typically covered with a light thermal insulation material and a building board on their internal side. Their additional thermal insulation can be done by additional thermal insulation on the external side of the structure. A variety of cladding options are available for this wall type.

Sometimes the brick walls were insulated internally with light-weight concrete insulation and rendering. The renovation options for this type of structure are similar to those of wall with normal internal insulation.

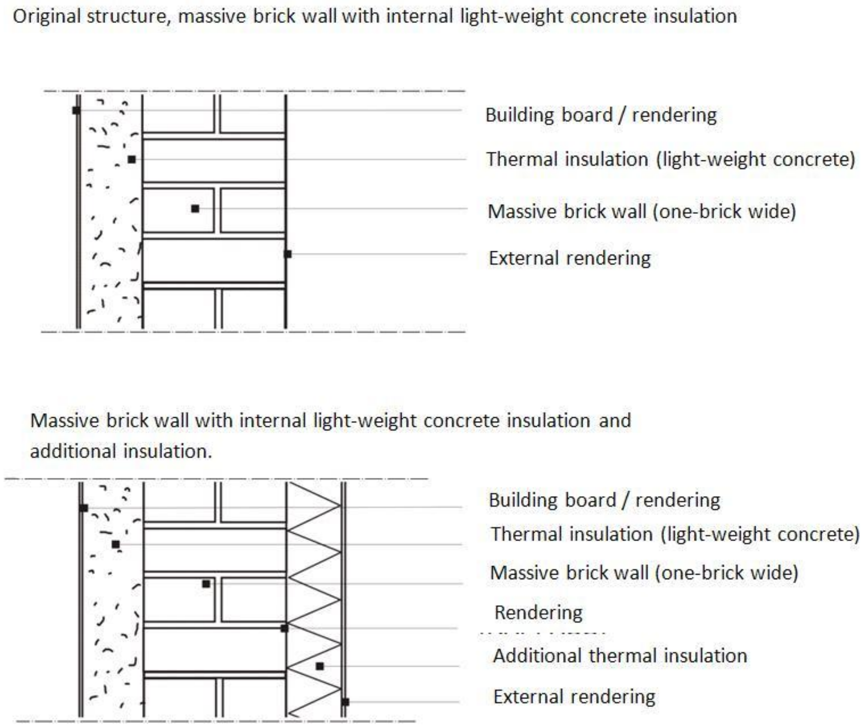
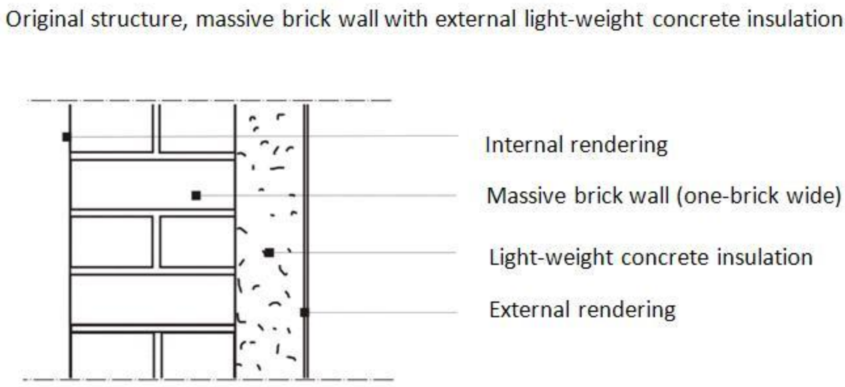


Figure 23. Massive brick wall with internal light-weight concrete insulation. Original structure and renovation with additional thermal insulation.

5.2.5 Massive brick wall with external insulation

One-brick wide massive brick walls with external lightweight concrete insulation are load-bearing walls. They are massive walls with two different materials. Their renovation is based on external thermal insulation. The façade structures can be chosen relatively freely.



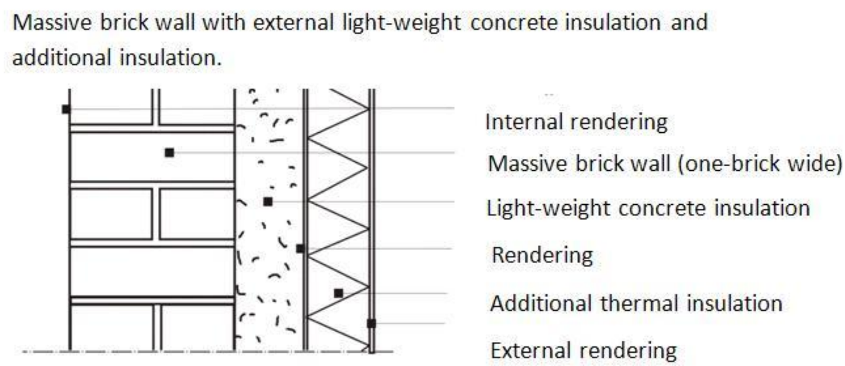


Figure 24. Massive brick wall with external light-weight concrete insulation. Original structure and renovation with additional thermal insulation.

5.2.6 Massive brick wall with external insulation and ½ brick façade

Massive brick walls with external thermal insulation and ½ brick façades are load-bearing walls. They can be renovated with either additional thermal insulation, or by replacing renovation methods. If the façade is in poor condition, it, and the underlying thermal insulation can be removed and a new thermal insulation material and façade can be chosen and installed freely.

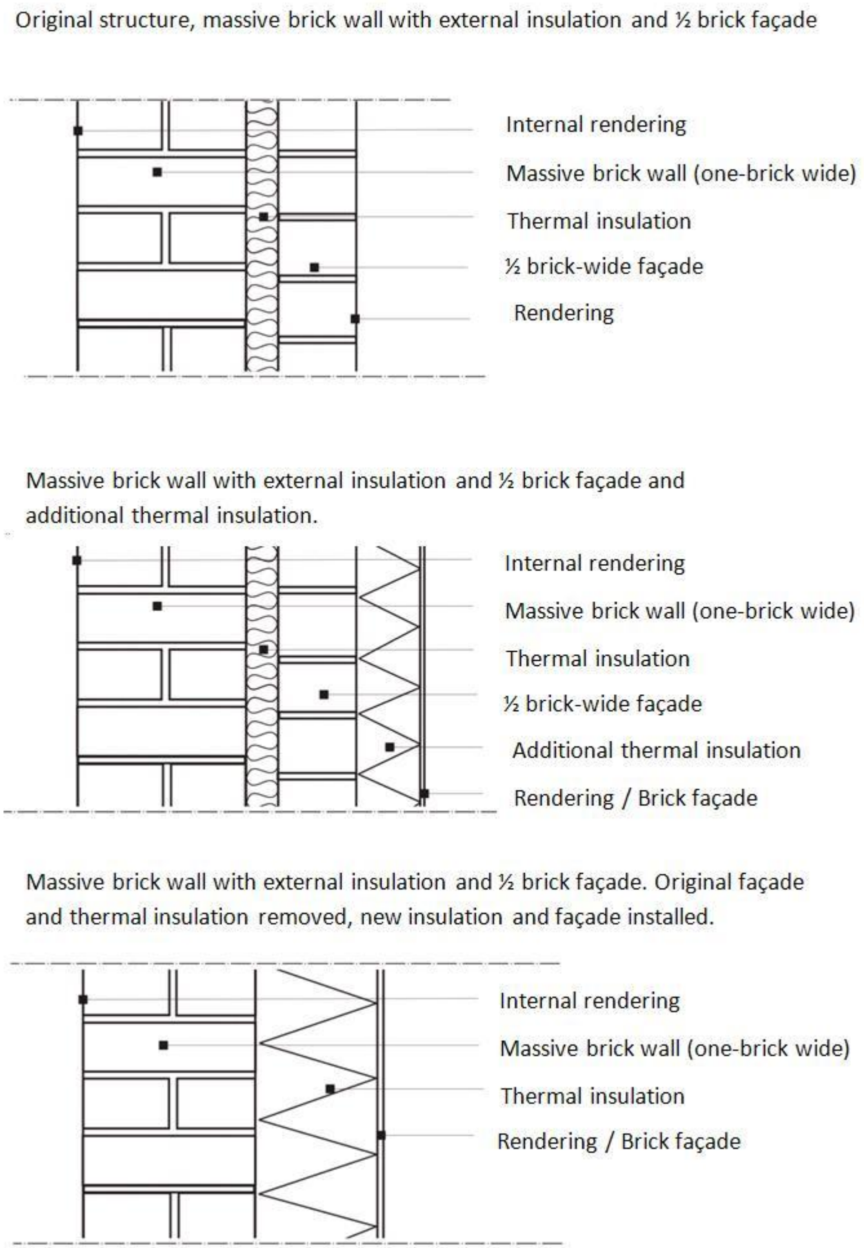
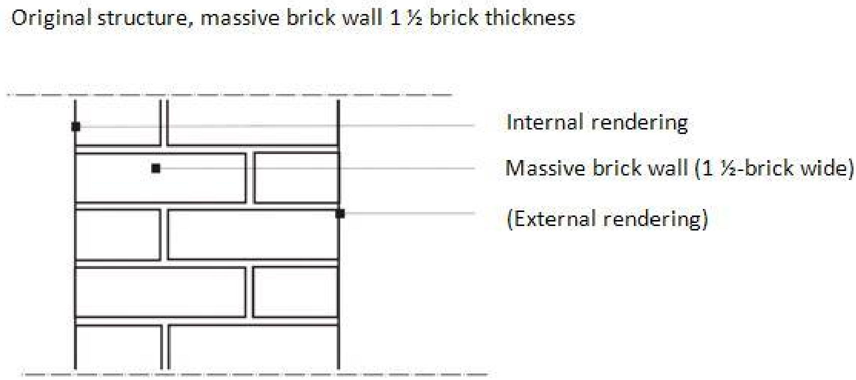


Figure 25. Massive brick wall with external insulation and ½ brick façade. Original structure and renovations with additional thermal insulation and replacing renovation.

5.2.7 1½ brick thick massive brick walls

Massive brick walls with 1 ½ brick thickness are heavy load-bearing walls. They can be renovated with additional thermal insulation. The new thermal insulation material and façade can be chosen freely.



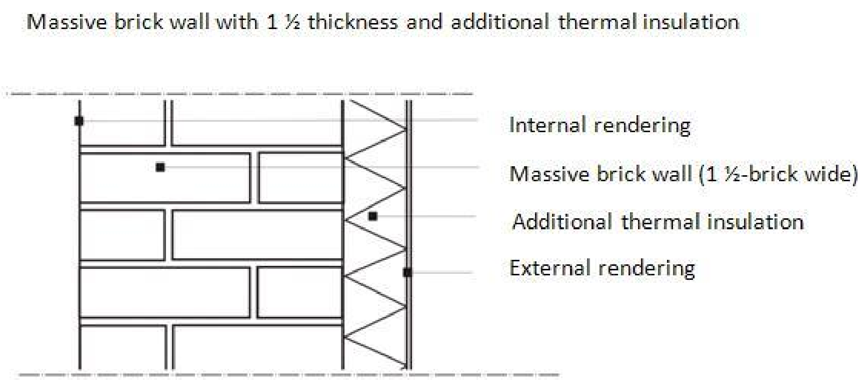


Figure 26. 1½ brick thick massive brick walls. Original structure and renovation with additional thermal insulation.

5.3 Examples of some problematic structures

5.3.1 Footing structures of 1960's–1980's

Base-floor structures with false-footings are very difficult structures, in terms of risks related to functionality and additional thermal insulation. These structures have been built with different external wall materials, such as timber-framed walls and brick walls.

In many cases, these structures have water- and heating pipes installed in the existing thermal insulation, whose rupture can cause massive renovation needs. Buildings with false-footings typically have their floor surface level very close to that of the surrounding ground-level. This means that there is a risk that water can enter the structures.

The internal walls of the building, which may be wood-framed, may stand on the floor slab. This leads to that the lower-sections of internal walls will also be damaged, when the thermal insulation gets moist. The structures may get moist very slowly, due to small leakages in piping, or small amounts of surface water penetration. This means that the moisture builds up slowly in structures, and it is detected only when they it has caused serious damage.

The structure can be made more secure by lowering ground level, and leading ground water away from the building. The piping inside thermal insulation also needs to be replaced with surface mounted installations inside room spaces. In addition, the wooden walls extending to the base floor should be replaced with masonry or concrete walls. At often times, one or more of the previously mentioned actions are not feasible to implement. This leads to that this structure is very risky, in terms of moisture.

These structures can basically be only insulated with insulation placed on top of existing floor structures, which will lead to, for example, adjusting vertical positioning of doors.

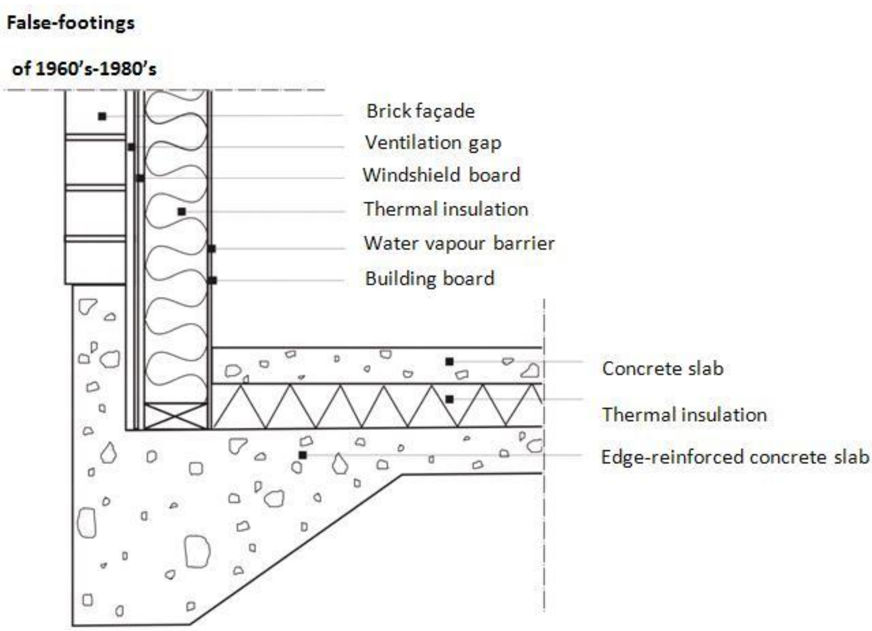


Figure 27. Problematic footing structures made in 1960's–1980's.

5.3.2 Edge-reinforced slabs of 1960’s–1980’s

Edge-reinforced floor slab with double-base floor is very close to the base-floor with false-footings, in terms of moisture-technical functionality, although a bit less risky. In general, the surrounding ground-level is below the floor-level, so surface-water penetration is not as high a risk as for false-footings. The renovation actions for this type of structure are the same as for the false-footings, excluding lowering the ground level. However, leading the surface water away from the building is an important aspect of managing the moisture-technical risks for all buildings.

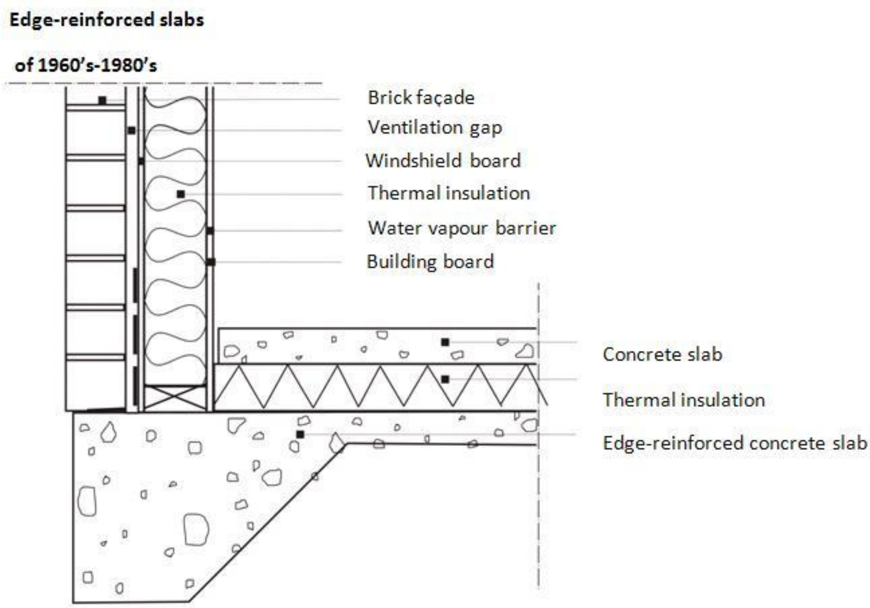


Figure 28. Edge-reinforced slabs from 1960's–1980's.

5.4 Detached wooden houses, built between 1940 and 1950

This section presents the additional thermal insulation methods of detached wooden houses built between 1940 and 1950. The wooden buildings built between 1940 and 1950 are typically wood-framed buildings, insulated with sawdust or wood-cuttings. The base-floors are usually ventilated.

These buildings may also have partial- or whole-building area sized basements. Based on past experience, the functionality of these buildings has been good even after renovation actions done in the 1960’s and 1970’s. These renovations usually included increased water installations, showers and saunas.

The increased water-use and water installations cause additional requirements for the functionality of structures and buildings. However, the buildings have worked well, despite of variable quality level of renovations, in terms of moisture-technical functionality. The functionality of these buildings is based on the extremely good drying properties of these buildings.

5.4.1 Base-floor of detached wood houses of 1940’s–1950’s

The following image presents a common base-floor type of detached houses of 1940–1950. The additional thermal insulation of these base floors can be made, for example, by adding wind shield mineral wool below the base floor. The installations can be made, thanks to the crawling space below the base floor in these buildings. If mice or other small animals are able to enter the crawling space, a dense steel mesh can be attached to the windshield board during its installation. The external wall and footings are insulated from the outside and the insulation material can be installed either with a separate frame or straight to the existing structure with mineral wool fixings.

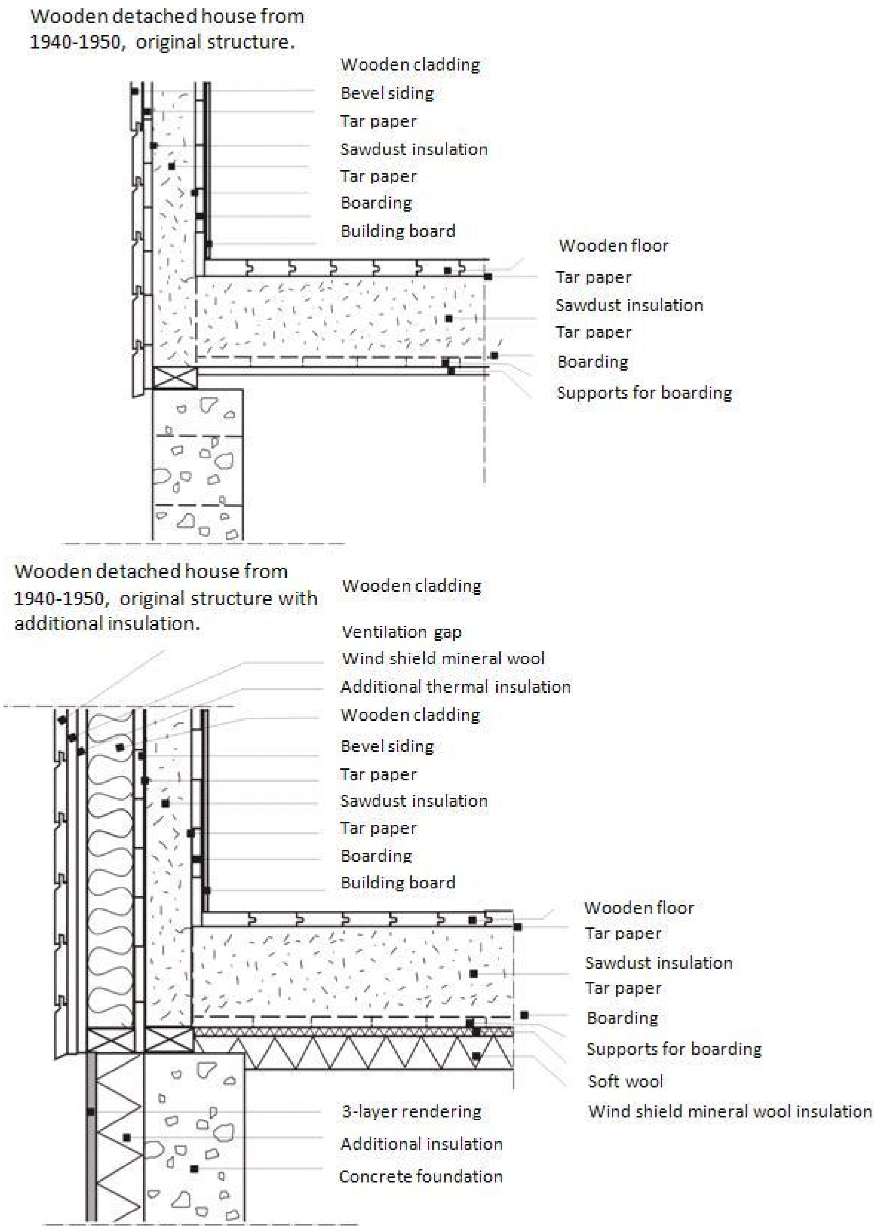


Figure 29. Base floor of detached wooden houses of 1940's–1950's, original structure and structure with additional thermal insulation.

The additional thermal insulation of these base-floors can be heat insulated by adding, for example, wind shield mineral wool below the base floor. The installations can be made, thanks to the crawling space below the base floor in these buildings. If mice or other small animals can enter the crawling space, a dense steel mesh can be attached to the windshield board during its installation. The external wall and footings are insulated from the outside and the insulation material can be installed either with a separate frame or straight to the existing structure with mineral wool fixings.

The external thermal insulation of wall starts with the removal of the existing structures. The ensure the drying capacity of the wall and to prevent rain water entering the thermal insulation layer, a ventilation gap is recommended. When installing additional thermal insulation, it should be remembered that the drying capacity of the wall decreases when additional thermal insulation is installed. Therefore it is recommended that the detailed design takes a close focus on preventing rain water from entering the structures.

5.4.2 Roof and intermediate floors of detached wood houses of 1940's–1950's

Roof and intermediate floors of 1940–1950 are typically sawdust or wood-chip insulated wood structures. The most challenging detail of the structure is the connection of intermediate floor and the retracted wall of the upper floor, where the floor joists "penetrate" the thermal insulation layer. In order to guarantee airtightness of the top floor, the air barrier of the heat-insulated wall should continue all the way to the bottom level of the floor joists, and, along them, until the external wall, joining its air barrier layer. However, the joists penetrate the air barrier layer, making seaming of the air barrier a challenging task.

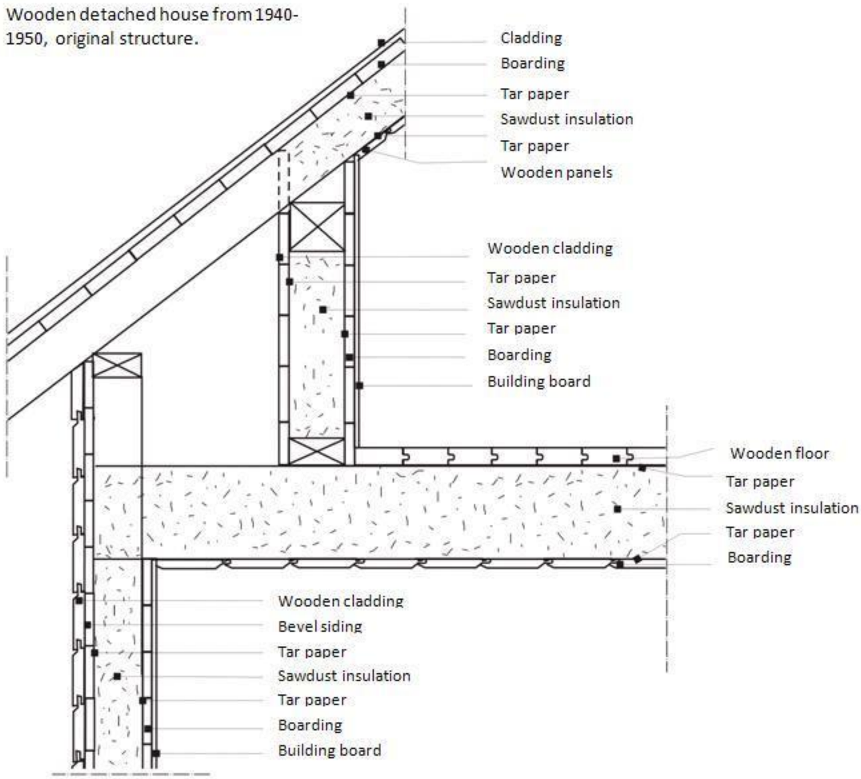


Figure 30. Roof and intermediate floors of detached wood houses of 1940's–1950's, original structures

Additional insulation can be applied to the roof and intermediate floors of 1940–1950 wooden buildings in the following way (Figure 31).

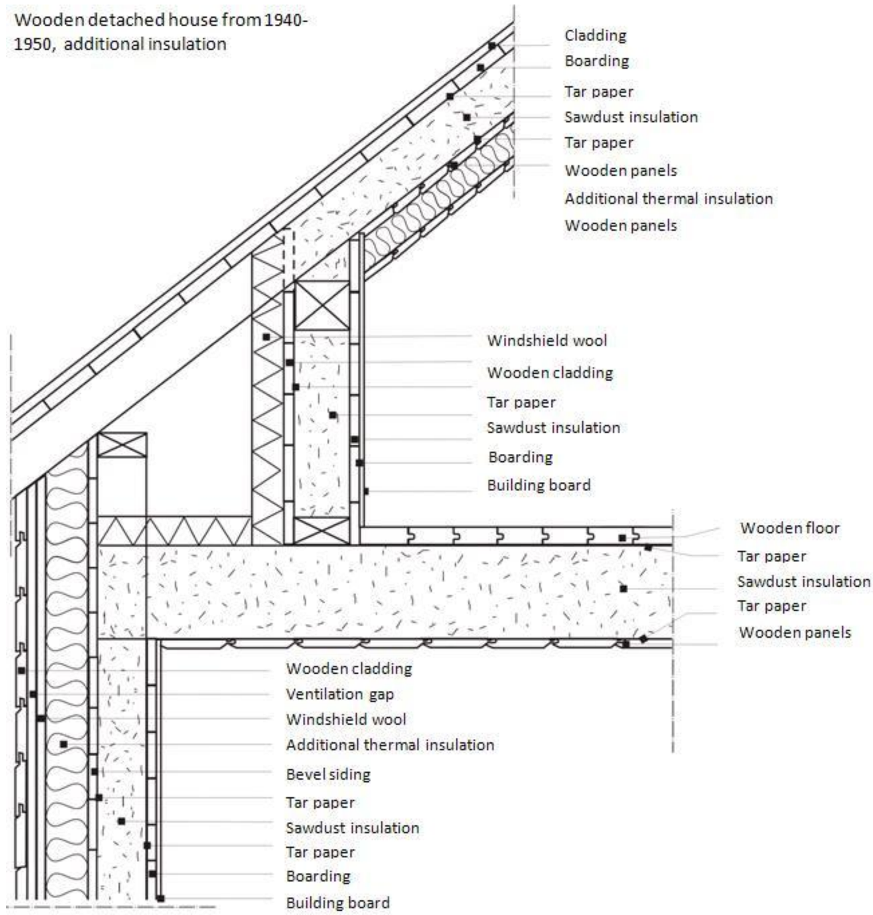


Figure 31. Roof and intermediate floors of detached wood houses of 1940's–1950's, with additional thermal insulation.

5.4.3 External wall structures of detached wood houses of 1940's–1950's

External wall of wooden house, built between 1940 and 1950. The original wall structure is sawdust of wood-chip insulated and the additional insulation can be applied to it by removing the external cladding, to the level of bevel siding. New insulation material can then be installed to the bevel siding with straight to the existing wall, with proper fixings, or with the help of a supporting timber-frame. The external cladding can be made as a wooden-cladding with an air-gap, or, with certain prerequisites, even as rendered surface.

If the insulation material is completely renewed, also the bevel siding and old thermal insulation material is removed. The structure is insulated, and attached through the mineral wool to the existing wall frame. The external cladding can then be made in a similar way, as in additional insulation.

When additional insulation is applied, or the insulation is renewed, it should be taken into account that the drying properties of the structure will be weakened. This underlines the importance of keeping water out of the structures

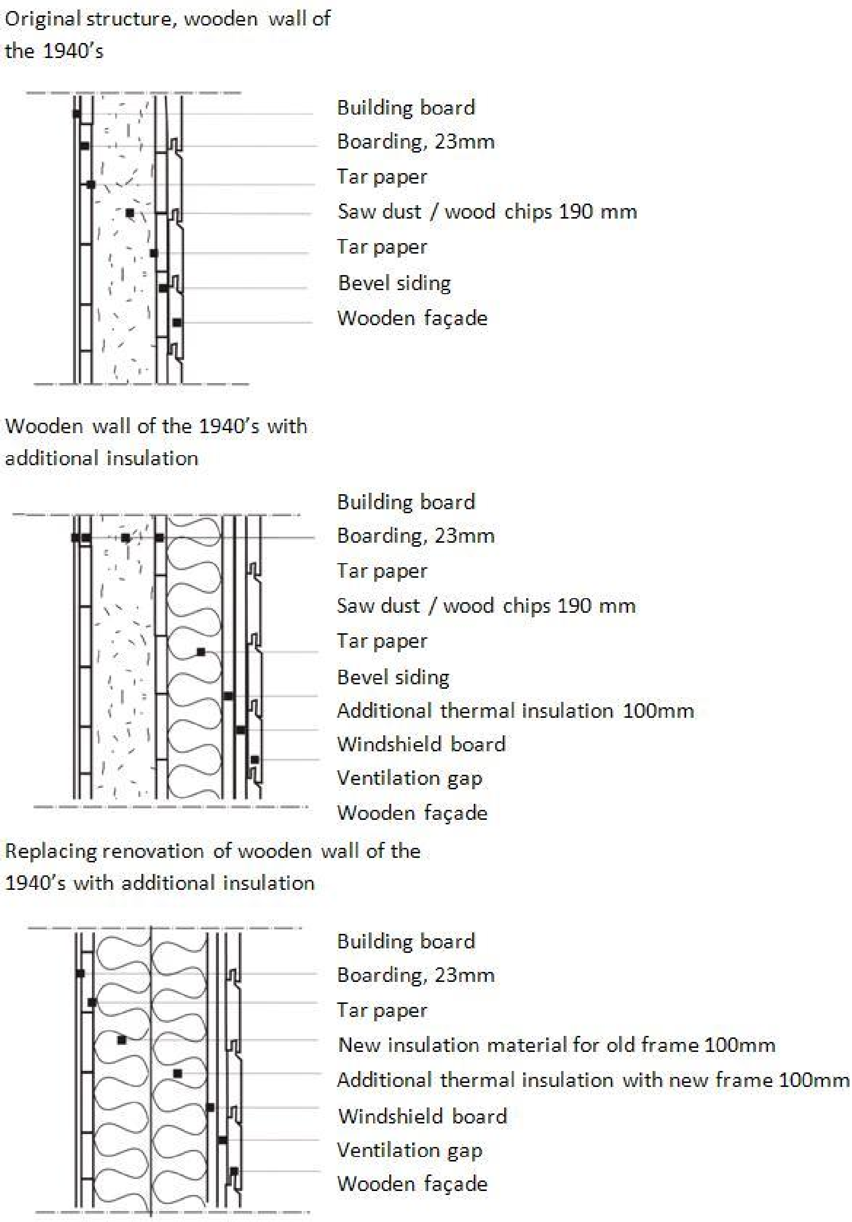


Figure 32. Wooden external walls of 1940's with two renovation alternatives.

5.5 Residential blocks of flats with prefabricated concrete structures

5.5.1 Renovation of gently sloped roofs

Unventilated, slightly sloped roofs can be renovated by adding a new thermal insulation layer on top of the old water insulation membrane, and adding a new cladding on top of insulation. The other option is to remove the old structures all the way to the load-bearing structure, and building a new roof structure as wanted. If the old insulation material is too soft, in terms of loadbearing capacity, or it has softened during its use, the only option is to remove old insulation.

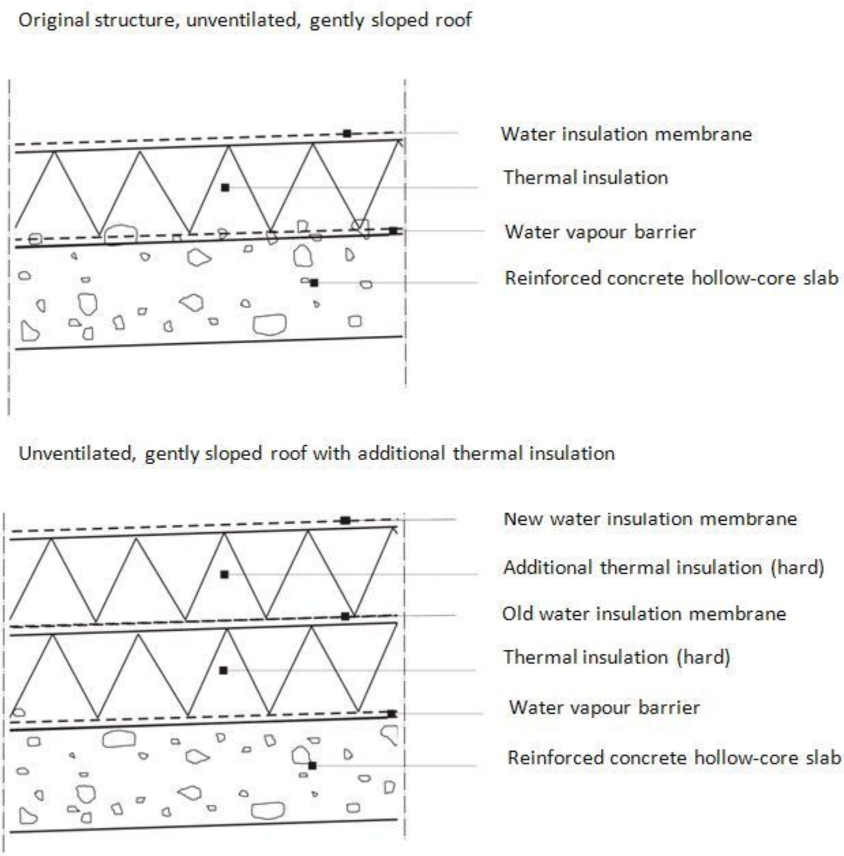


Figure 33. Unventilated, gently sloped roof. Original structure and renovation with additional thermal insulation.

5.5.2 Prefabricated external walls

Additional insulation of concrete-sandwich elements is done at the external side of the concrete elements, and the façade material can be chosen freely. However, the most common façade material is rendering. The additional insulation methods have things to improve, particularly at the edges of openings of external walls. The current solutions often leave the edges of openings in contact with external air, leading to diminished effectiveness of the additional insulation.

Renewing of the structure is done by removing the existing external shell and the insulation material of a concrete sandwich element. The external side of the internal shell of a sandwich-element is usually uneven, and it needs to be straightened before the heat insulation can be installed.

The additional insulation layers and external cladding can be installed in a number of ways. The insulation material can be installed on site, and the cladding can be done with rendering. Also, a supporting frame can be used for insulation, and façade installation. Also, prefabricated solutions exist, in which the additional insulation material, façade, and possibly also windows and doors are ready-installed. The prefabricated solutions require often exact measures of the dimension of façades, placing of openings, and so on. For exact measurements, for example, laser scanning may be used.

Also other external wall types are commonly used in residential blocks of flats. However, these are already discussed in the previous sections.

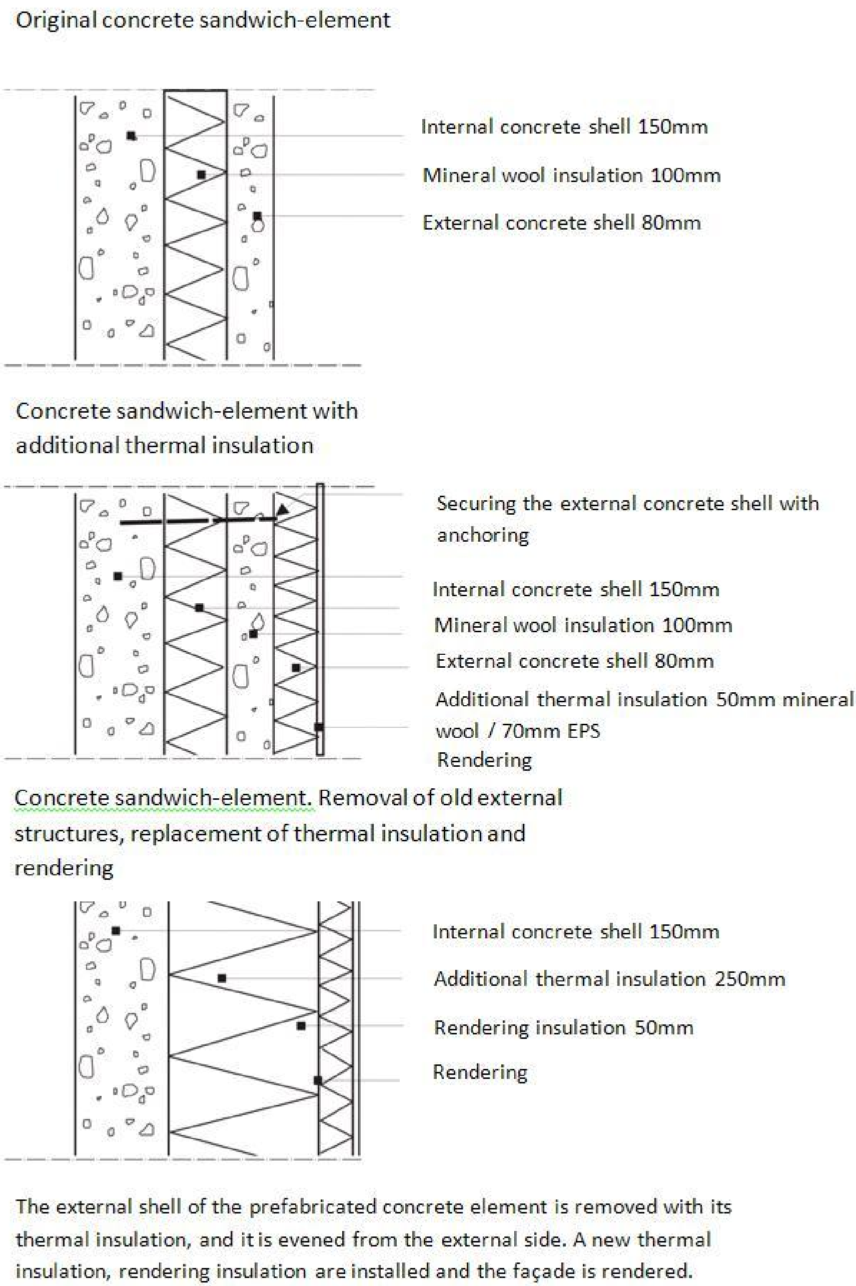


Figure 34. Renovations of prefabricated concrete sandwich-walls.

5.6 Summary

Some of the methods available for additional thermal insulation, and renewing of structures, were presented. These were only examples, and the methods presented here can also be combined, and also completely different methods exist.

Renewal of structures by demolition of the existing external wall requires usually that the façade is in such a poor shape that the façade itself would require excessive repairs. If the façade is removed, the cost of additional insulation is reasonable. The renovation solution may be decided upon connections between

Aesthetical issues may lead the selection of renovation method, or lead to significant additional work on the visible parts of the preserved, existing structures. The residential blocks of flats of today often have a ground floor, which contains the common facilities and spaces. The external walls of such spaces are typically poorly insulated, and adding these into the renovation plan might be very important. The original planning idea of such spaces has been that these spaces serve as semi-heated spaces. However, the use of such spaces has typically changed, and they are currently used for functions requiring almost normal room temperatures.

6. Environmental impact of materials in building refurbishment

6.1 Objective

The objective of the study presented in this Chapter was to assess the significance of building materials in building renovation in terms of primary energy, CO_2eq and consumption of raw-materials. The environmental impact of renovation materials was compared to the saved environmental impact due to the energy saving achieved by renovation.

6.2 General

Energy performance in new constructions has been regulated during the previous years by tightening heat insulation levels, by reducing air leakage rate and by taking in use heat recovery from exhaust air. The new directive (2010) also sets requirements for existing buildings. However, existing building stockis old and buildings need renovation and refurbishment to improve their performance and update their energy efficiency.

Various refurbishment methods, material types, insulation levels and achieved energy efficiency result in the use of different material quantities, which all cause different impacts into the environment.

Typical refurbishment methods are:

- wall insulation externally or internally
- replacement renovation where building façade and insulation replaced with materials having better performance
- roof and base floor insulation
- window replacement
- adjustments in HVAC systems or total renewing of HVAC.
- Prior to the selection of right refurbishment methods one should estimate what is the technical condition, deterioration rate and remaining service life of the existing building. The most radical method is demolition prior to

new construction. This may the only practical solution when the building condition survey shows that:

- refurbishment work is very extensive (material and money consuming),
- the building design and partitions are old-fashioned which might not fulfil required performance also after renovation
- the reasonable energy saving is not achievable because of the old existing building details and uncontrolled ventilation which might remain also after renovation
- additional spaces would not be constructed because of an inadequate load bearing capacity of an existing building frame.

Environmental impact for the renovation concepts is assessed with the help of life cycle assessment (LCA). Three main indicators: carbon footprint (CO_2eq), non-renewable raw-material and fossil energy consumption were chosen to show material relevance compared to the building operation and energy saving. The main assumption was that the existing buildings was poorly insulated and urgently need refurbishment.

6.3 Approach

The approach for the significance study of material environmental impacts in renovation is made through the study of residential a multi-storey building and an attached building in Finland, with typical structures, materials and volumes.

Refurbishment options

It is assumed that majority from energy renovation and refurbishment projects focus on additional insulation installation, which is normally installed as an additional layer to the building façade. In these cases, existing load bearing structure will remain the same as it was before renovation but insulation material, thickness and façade material are renewed.

In some cases, refurbishment is not a good option and the only reasonable solution to improve building performance, is to demolish some parts or the whole building.

This study considers:

- Two refurbishment methods
  - External insulation – with new additional insulation, new façade and roof
  - Replacement renovation – with replaced and additional insulation and with the new façade with the same type
- Demolition level
  - Partly demolition and renovation (case multi-storey concrete building)
  - Total demolition and new construction
- Two refurbishment targets

- low energy building structures,
- passive energy building structures.

Environmental impact was assessed for the building refurbishment and 50 years' operation. Figure 35 shows the life cycle phases considered in the assessment.

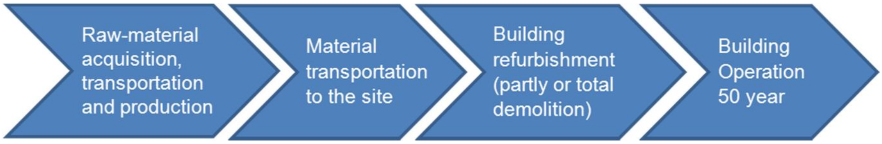


Figure 35. Building life cycle for refurbishment cases.

Refurbishment targets

Goal for the renovation was to improve energy efficiency to the level of low or passive energy houses. U-values for existing building structures and for refurbishment are presented in Table 17.

Table 17. U-values for building assessment.

Structure	Existing structure	Low energy structure	Passive structure
Exterior wall	0.6	0.14	0.085
Roof	0.39	0.10	0.075
Base floor	0.48	0.15	0.15
Window	2.79	0.7	0.7

Demolition prior to construction

Demolition of multi-storey concrete building is modelled either as total demolition or dismantling and demolition of external concrete layer. Environmental impact from demolition is based on the real case study [Perälä & Koski 2010], multi-storey concrete building demolition in Kuopio. Demolition and dismantling in the case of an attached wooden frame building is not taken into account.

Material types used

According to the statistics in residential block of flats the mostly used load bearing material is concrete, which represents 83% from total floor area within the building type category block of flats . Because of this majority in load bearing material use, the typical multi-storey buildings in this assessment is concrete building with load-bearing concrete elements. The façade material type in multi-storey concrete building refurbishment is most likely new concrete or rendering coat.

However, in attached and detached building type, the majority of the load bearing material is a wood which represents accordingly 63% and 88% from total floor area within the attached and detached building categories. According to this statistics small houses in Finland have wooden load bearing structure but main façade material is either wood or masonry work.

According to the Finnish Façade Association survey the mostly used facade material in renovations is wood (adopted [Vainio et al. 2005], Table 18). Wood façade is chosen also for the assessment of existing attached buildings survey.

Table 18. New facades for existing buildings (adopted table from Finnish Facade Association survey [Vainio et al. 2005].

Façade type	New façade types for existing buildings	Share from total
	1000 m^2	
Concrete facade	190	3%
Rendering facades from which	570	10%
3 layer rendering	290	
Brick facades	460	8%
Metal facade	550	9%
Wooden facade	**4070**	**68%**
Other, boards etc.	130	2%
Total	6000	100%

Assumptions for refurbishment

Refurbishment options, to achieve low energy or passive building structures, are theoretical calculations about the needs to increase wool thicknesses and new coating. It is assumed that renovation doesn't cause any buildability and structural problems:

- wall insulation externally is possible also for the cases where the insulation thickness grows remarkable (demand for special fasteners or wider foundation is not taken into account)
- in the case of slope roof renovation it is assumed that there is a space for additional insulation
- in the case of base floor insulation, external insulation underneath of the existing base floor doesn't cause assembly and other problems.

6.4 Environmental impact

Environmental impact assessment is based on Life cycle assessment method (LCA). LCA is the procedure where potential environmental impacts are studied throughout the product life cycle.

Many environmental impact categories exist. In this project greenhouse gas emissions and carbon footprint, fossil energy and non-renewable raw material consumption are chosen as the indicators for sustainable refurbishment.

Carbon footprint is the amount of carbon dioxide and other greenhouse gases which are quantified by using indicators such as Global Warming Potential [IPCC 2007b]. Carbon footprint is calculated according to the next formula:

$$CO_2 eq. = 1 \cdot CO_2 + 25 \cdot CH_4 + N_s O \qquad (3)$$

Environmental impact for renovation materials and energy based mainly on VTT's database. For heating and average Finnish district heat and average Finnish electricity is used. The used values are given in Appendix F.

6.5 Buildings, structures and materials for refurbishment

6.5.1 Model buildings

Model buildings are typical multi-storey and attached buildings with typical structures and sizes. It is assumed that they located in the Helsinki metropolitan area, in Southern part of Finland.

Multi Storey building

Model building for multi-storey type is a 5-storey apartment building with the total floor area 1,850 m^2 and building volume 5,520 m^3. The floor height is 3 m, and the building contains 29 apartments from which 19 are one room apartments, 9 are two-room apartments and one is a three room apartment and one storage room in ground floor. The number of inhabitants is 40 persons.

Attached building

Model building for attached type is 1-sorey row house with total floor area 540 m^2 and building volume 1,620 m^3. The floor height is 3 m and the building contains 6 dwellings with average size 90 m^2. The number of inhabitants is 13 persons.

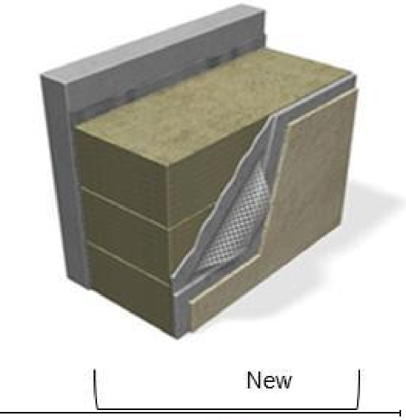
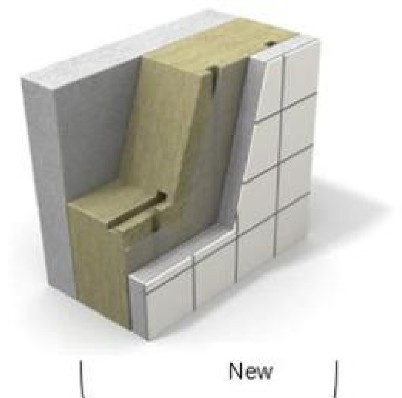
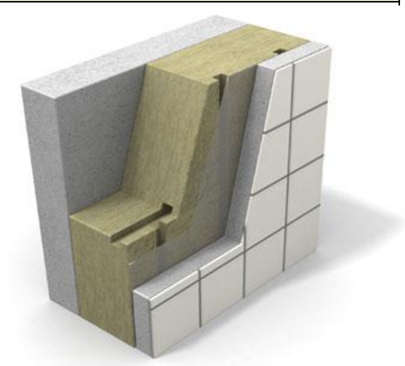
Table 19. Existing building structures and sizes and main material types.

Building envelope	Multi-storey concrete building (5-storey building)		Attached wooden frame building (1 storey building)	
	m^2	Structure	m^2	Structure
Exterior wall	900	Load bearing concrete element	351	Load bearing wooden frame, wooden facade
Roof	370	Flat roof with asphalt mastics	556	Pitched roof with concrete tiles
Base floor	370	Ground slab	540	Timber structure
Window	170	Double or triple pane window	63	Double or triple pane window
Partition floor	1480	Hollow core slab	–	–
Partition walls between apartments	900	Concrete	150	Load bearing wooden frame with gypsum boards

6.5.2 Wall types and refurbishment

Wall refurbishment covers external insulation and new façade installations or replacement case where outer external wall layer and old insulation removed and new insulation and façade installed. Table 20 shows the wall renovation cases for multi-storey and attached buildings. Wall type comparison is made according to the insulation level; low energy- and passive energy structure wall. Material layer thicknesses and quantities are given in the Appendix G.

Table 20. Renovation types for multi-storey and attached building wall.

Multi-storey concrete building (M)	
W1M – External insulation and 3-layer rendering installed to the existing concrete façade. • old outer layer bolted to inner layer because of corrosion of steel links • retrofit insulation is fixed on an old outer surface • installation of new three layer rendering	
W2 M – Replacement renovation and new concrete façade • old outer layer removed, • old insulation material removed • retrofit insulation is fixed on an inner layer • new outer concrete with ceramic tile installed	
New multi-storey building (New M)	
New M – demolition prior to new construction building demolished • new concrete sandwich element with ceramic tile constructed	

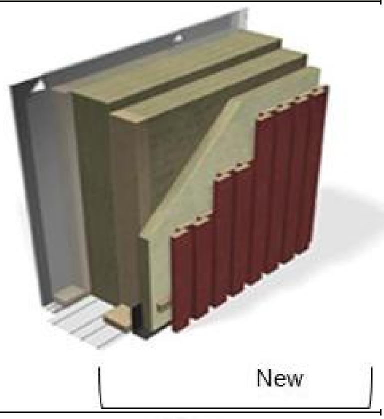
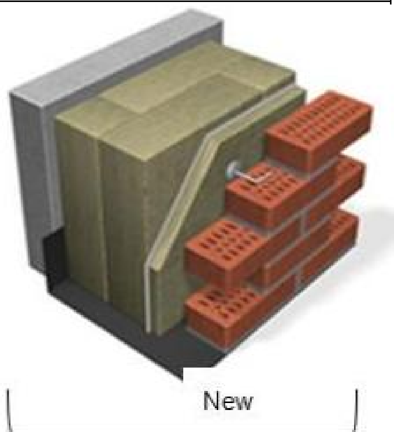
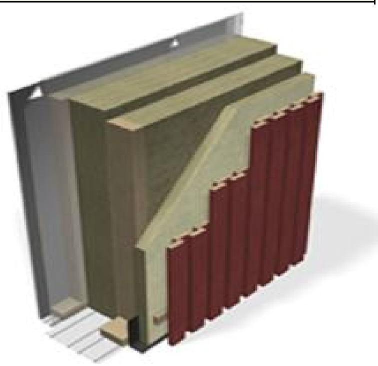
Attached wooden frame building (A)	
W1A – Replacement renovation and new wooden facade (double wooden stud frame) • old outer wooden façade layer removed • old insulation removed • retrofit insulation is installed • new outer wooden façade installed	
W2A – Replacement renovation and new masonry facade • old outer masonry layer removed • old insulation material removed • retrofit insulation is installed • new outer masonry layer installed	
New attached wooden frame building (New A)	
New A – demolition prior to new construction • new wooden frame building with wooden façade constructed	

Figure 36, Figure 37 and Figure 38 show the carbon footprint, fossil energy consumption and non-renewable raw material consumption for exterior wall refurbishments. It is assumed that material transportation to the building site is 50 km, insulation material loss during installation is 2% and wood based material loss 5%.

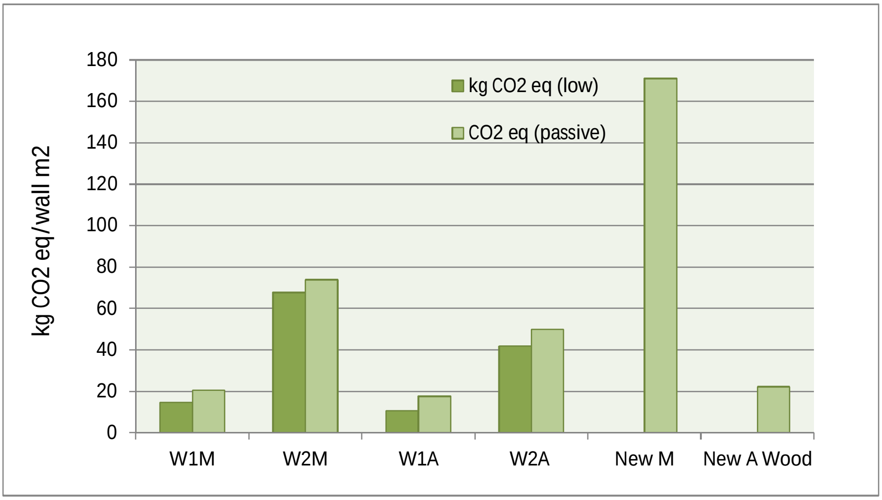


Figure 36. Carbon footprint for wall refurbishment materials and demolition when replacement refurbishment is used (case W2M, concrete outer layer demolition).

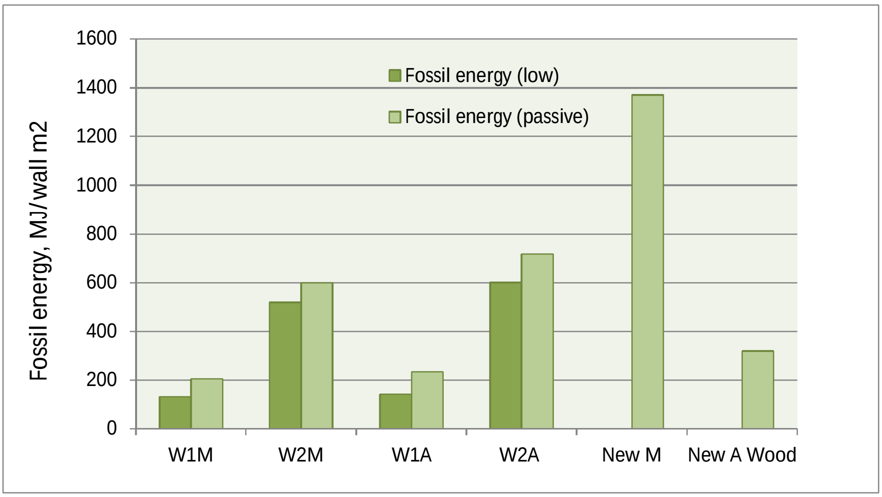


Figure 37. Fossil energy consumption for wall refurbishment materials and demolition when replacement refurbishment is used (case W2M, concrete outer layer demolition).

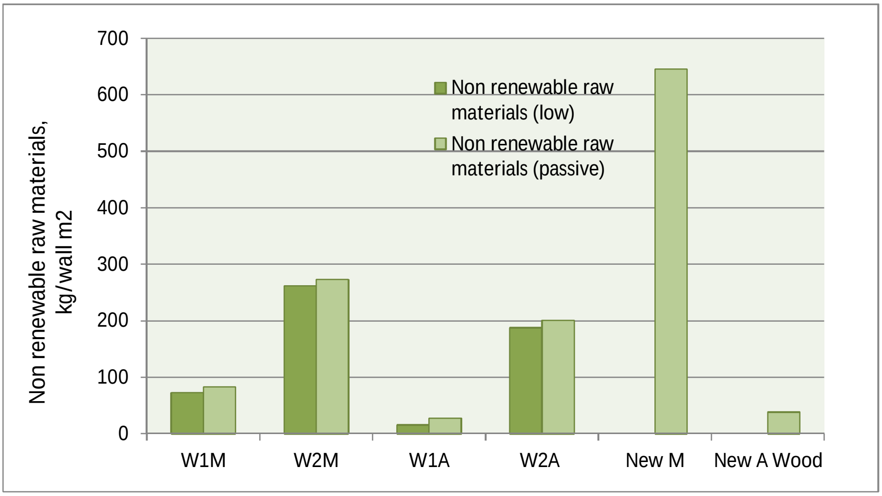
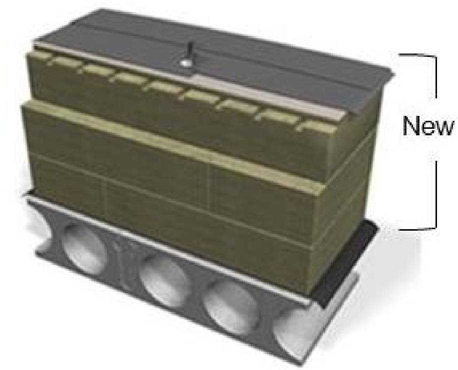
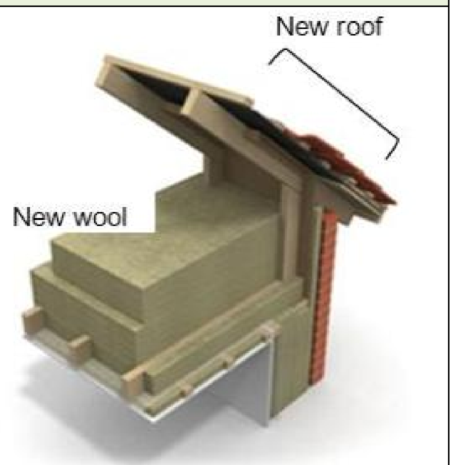


Figure 38. Non-renewable material consumption for wall refurbishment materials and demolition when replacement refurbishment is used (case W2M, concrete outer layer demolition).

6.5.3 Roof types and refurbishment

Roof refurbishment covers additional insulation layer and new roof covering materials. Table 21 shows possible options for multi-storey building and for attached buildings. Roof type comparison is made according to the insulation level; low energy- and passive energy structure. Material layer thicknesses and quantities are given in the Appendix H.

Table 21. Renovation types for multi-storey and attached building roof.

Multi-storey concrete building (M)	
R1M – New insulation and new asphalt mastic roof cover (heavy roof) • old roof mastics and insulation removed • retrofit insulation and new asphalt mastic cover installed	
New multi-storey concrete building (New M)	
New M – demolition prior to new construction • building demolished • new hollow core slab roof constructed	
Attached wooden frame building (A)	
R1A – Additional insulation and new roofing tile (semi light roof) • old concrete tile removed • old wooden batten removed • old insulation and fibre board removed • retrofit insulation is installed • new roof covering sheeting assembled • new wooden batten installed • new concrete tile assembled	

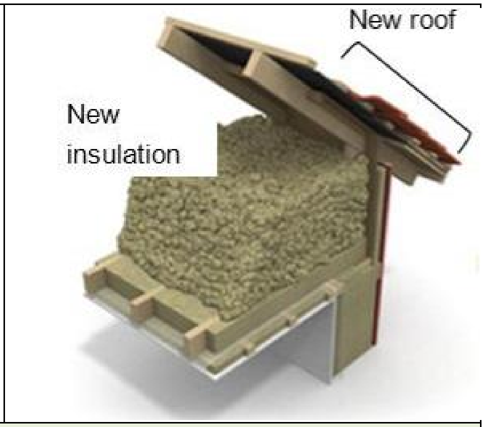
<table>
<tr><td>R2A – Additional insulation + new asphalt mastic roof covering (light-weight roof)
• old concrete tile removed
• old wooden batten removed
• old insulation and fibre board removed
• new mineral wool loos materials blew
• new wooden boarding assembled
• new asphalt mastics assembled</td><td>
</td></tr>
<tr><td colspan="2">New Attached wooden frame building (New A)</td></tr>
<tr><td>New A – demolition prior to new construction
• building demolished
• new wooden structures and new concrete tile roof constructed</td><td></td></tr>
</table>

Figure 39, Figure 40 and Figure 41 show carbon footprint, fossil energy consumption and non-renewable raw material consumption for roof refurbishment options. It is assumed that material transportation to the building site is 50 km, insulation material loss during installation is 2% and wood based material loss 5%.

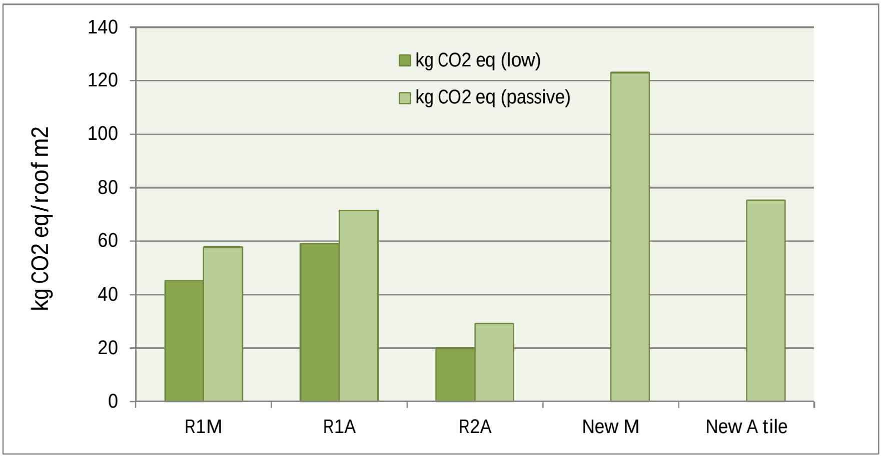


Figure 39. Carbon footprint for roof refurbishment.

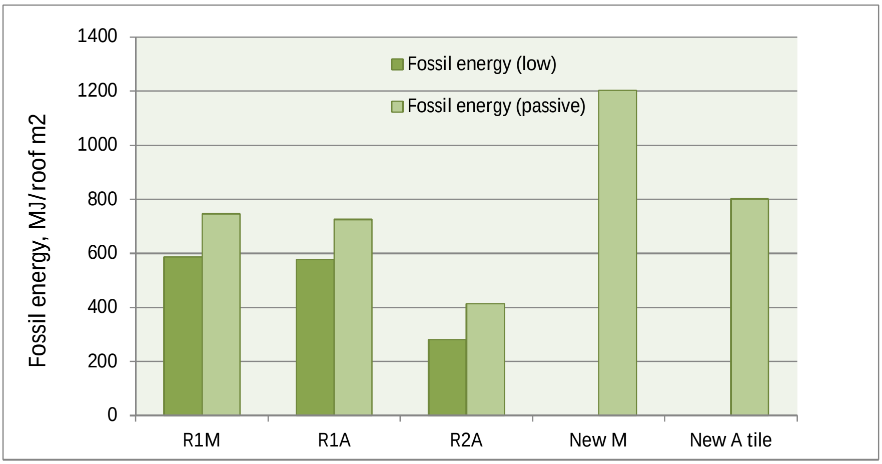


Figure 40. Fossil energy consumption for roof refurbishment materials.

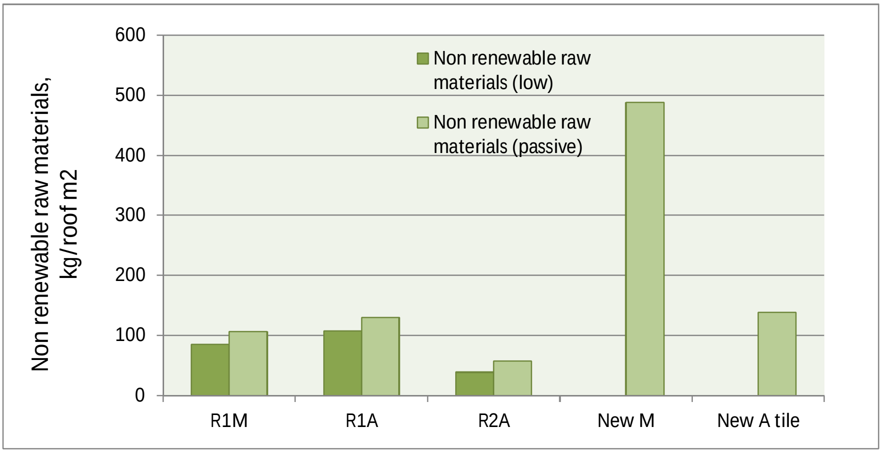


Figure 41. Non-renewable material consumption for roof refurbishment materials.

6.5.4 Window refurbishment

One possible renovation action is window replacement with better insulation capacity. Window types are presented in Table 22 and environmental parameters in Table 23..

Table 22. Existing window type and window type in renovation.

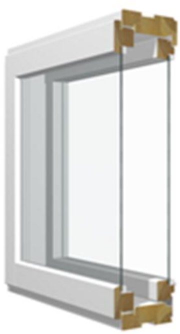
Existing window	Energy efficient window type
Structure for existing window: double or triple pane window, pine timber frame. 	Structure for quadruple pane window: 2 pcs. Low-E glass, two double pane IG-units, argon gas filling, aluminium outer surface. 

Table 23. Environmental impact for window used in renovation (energy efficient type).

	CO_2 eq kg/m^2	Fossil energy MJ/m^2	Non-renewable raw materials kg/m^2
Wooden aluminum window, used in refurbishment cases	58	932	49

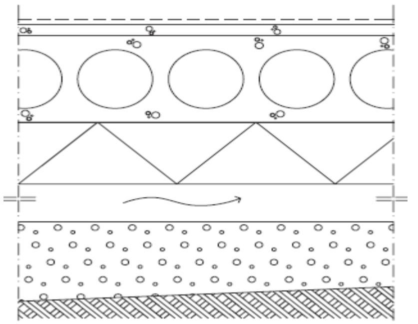
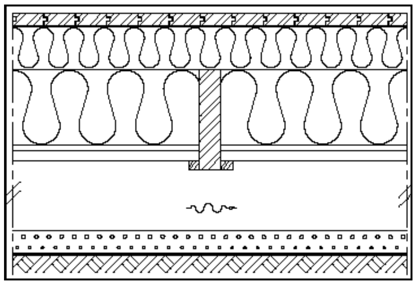
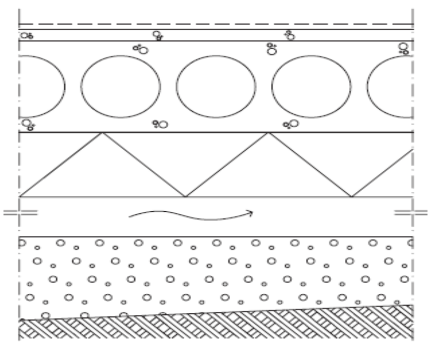
6.5.5 Base floor type and refurbishment

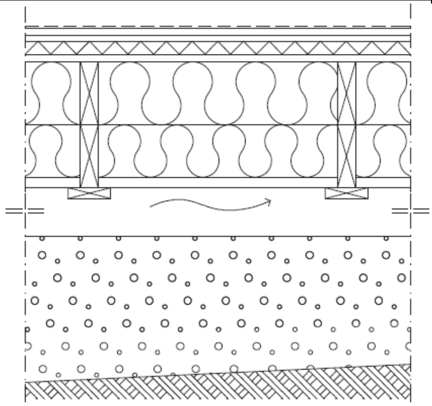
The refurbishment of base floor insulation to the low or passive level standard is in many cases almost impossible. Base floor insulation problems are related to the lack of space for insulation, structural issues concerning door openings and also problems to reach the old insulation layer without massive destructive operations (insulation layer is behind of the concrete slab).

However in this assessment it is assumed that the buildings have reachable subfloor space and additional insulation layer underneath of the base floor structure is possible. Options for base floor renovation are shown in Table 24. Material layer thicknesses and quantities are given in the Appendix I.

Figures 41–44 shows carbon footprint, fossil energy consumption and non-renewable raw material consumption for the base-floor refurbishment. It is assumed that material transportation to the building site is 50 km, insulation material loss during installation is 2% and wood based material loss 5%.

Table 24. Renovation type for multi-storey and attached building base floor.

<table>
<tr><th colspan="2">Base floor in multi-storey building case (BM)</th></tr>
<tr><td>BM – Additional external insulation
• New parquet floor assemble
• Additional insulation installation underneath of the base floor</td><td></td></tr>
<tr><th colspan="2">Base floor in attached building case (BA)</th></tr>
<tr><td>BA – Additional external insulation
• New parquet floor assembled
• Additional insulation installation underneath of the base floor</td><td></td></tr>
<tr><th colspan="2">New Base floor in multi-storey building case (BM New)</th></tr>
<tr><td>New M – Building demolition prior to construction
• Building demolished
• New concrete based floor constructed
• New parquet floor assembled</td><td></td></tr>
</table>

New base floor in attached building case (BA New)	
BA New – Demolition of an existing building prior to construction • Building demolished • New base floor constructed (timber based construction) • New parquet floor assembled.	

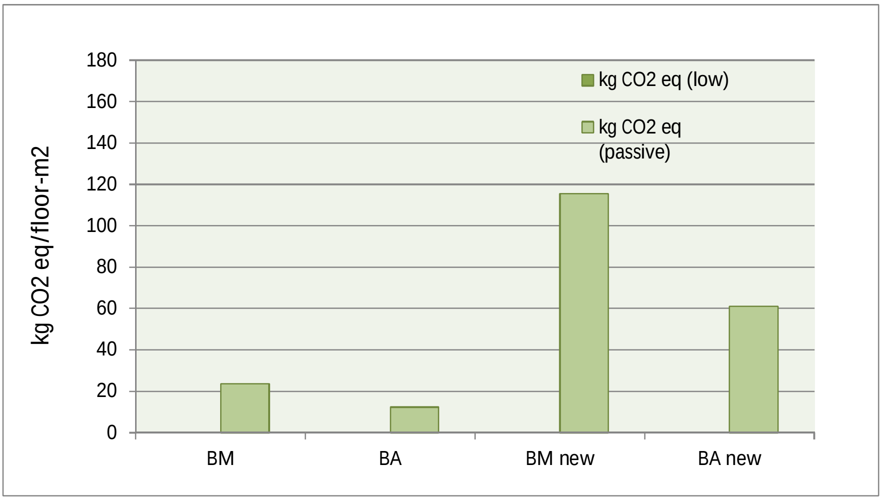


Figure 42. Carbon footprint for base floor refurbishment.

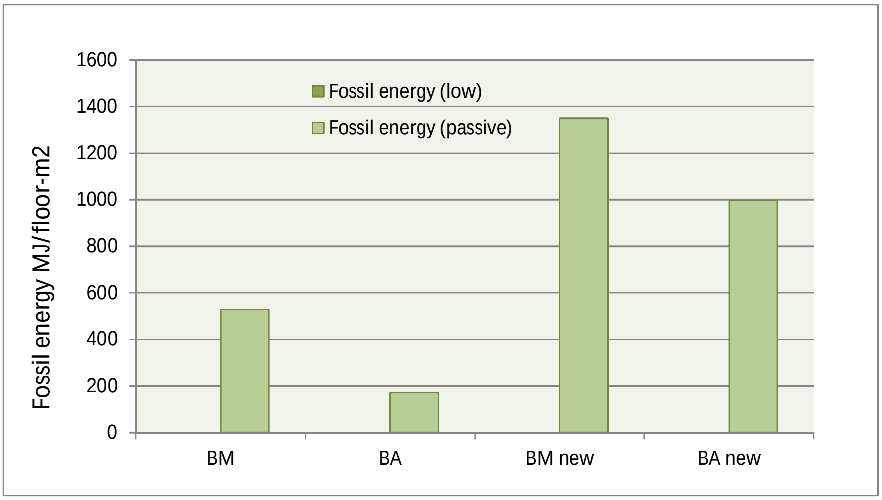


Figure 43. Fossil energy consumption for base-floor refurbishment materials.

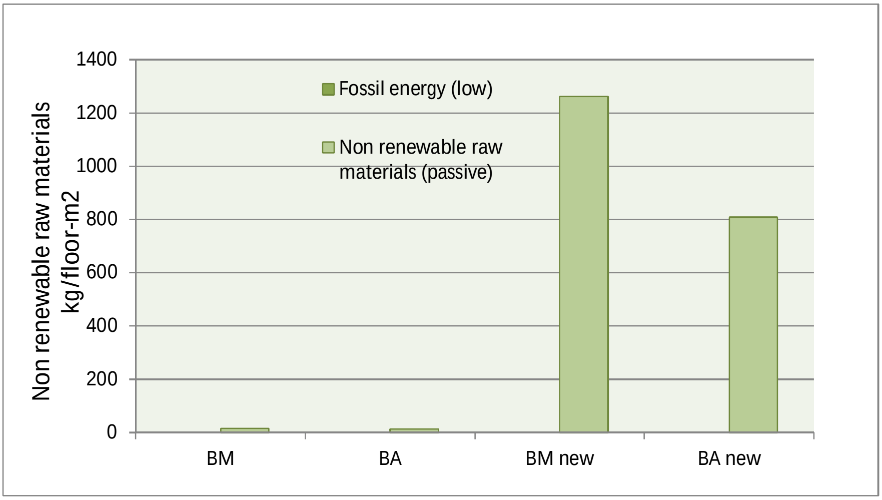


Figure 44. Non-renewable material consumption for base-floor refurbishment materials.

6.5.6 Other structures for new buildings

Environmental impact from building refurbishment was compared with the case where existing building is demolished and new building constructed. For the new construction also partitions need to be constructed. Table 25 shows the partition types for multi-storey and for attached building and Table 26 their environmental impact.

Table 25. Partition wall and partition floor types for new construction.

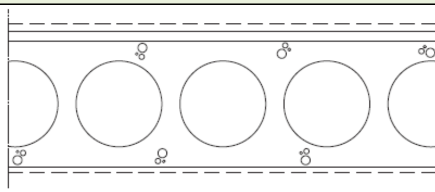
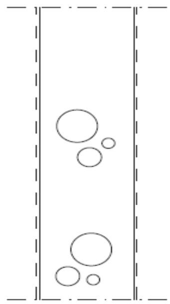
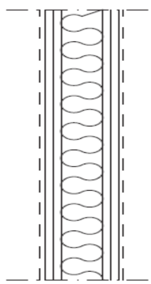
New Partition floor in multi-storey building case	
Demolition of an existing building prior to construction • Building demolished • New hollow core slab with parquet floor constructed	
New partition wall between apartments (case new multi-storey building)	
Demolition of an existing building prior to construction • Building demolished • New concrete partition wall constructed	
New partition wall between apartments (case new attached building)	
Demolition of an existing building prior to construction • Building demolished • New insulated wooden frame double-gypsum board wall constructed	

Table 26. Environmental impact for partition wall and partition floor.

	CO_2 eq kg/m^2	Fossil energy MJ/m^2	Non-renewable raw materials kg/m^2
PW M – Partition wall for multi-storey building	98	801	478
PW A – Partition wall for attached building	29	128	23
PF M – Partition floor for multi-storey building (attached building is one-storeyed building with no partition floor)	74	579	388

6.6 Operational energy

Operational energy for existing building, for renovated building (low and passive envelope structures) and for new building is calculated with the help of WinEtana tool. The following assumptions were made for energy calculations:

- Water central heating distribution system is used and heating type is average district heat in Finland.
- Leakage air flow rate for existing buildings is 0.2 1/h, for low energy building envelope is 0.1 1/h and for passive energy building envelope is 0.024 1/h.
- heat recovery rate for new buildings is 75% and leakage air flow rate is 0.024 1/h.
- Electricity consumption considers fridge and freezer, electrical sauna stove (one sauna for the whole multi-storey building and one per apartment in attached building), entertainment devices, food preparation, laundry, dishing machine, car heating, outdoor lightning, room lightning and air exhaust. For multi-storey building also electricity consumption from the use of elevator is taken into account.
- Electricity consumption for existing building is based on the assumption that all devices and appliances are old and their energy efficiency class is D.
- Electricity consumption for renovated building is based on the assumption that all devices and appliances are new and their energy efficiency class is A.

Energy simulation results for multi-storey and attached building are given in Table 27 and Table 28.

Table 27. Operational energy for existing multi-storey building (29 apartments), for renovation and for new construction.

	Existing building MWh/a (kWh/m^2)	Renovation, Low energy building envelope MWh/a (kWh/m^2)	Renovation, Passive structure building envelope MWh/a (kWh/m^2)	New, Passive energy building MWh (kWh/m^2)
Heating energy (district heating)	241 (130)	93 (50)	70 (38)	18 (10)
Service water heating	94 (51)	94 (51)	94 (51)	94 (51)
Electricity	82 (44)	55 (30)	55 (30)	55 (30)
Total	417	242	219	166

Table 28. Operational energy for existing attached building (6 apartments), for renovation and for new construction.

	Existing building MWh/a (kWh/m^2)	Renovation, Low energy building envelope MWh/a (kWh/m^2)	Renovation, Passive structure building envelope MWh/a (kWh/m^2)	New, Passive energy building MWh (kWh/m^2)
Heating energy (district heating)	125 (233)	43 (80)	34 (63)	15 (27)
Service water heating	28 (51)	28 (51)	28 (51)	28 (51)
Electricity	18 (34)	13 (25)	13 (25)	15 (28)
Total	171	84	74	57

6.7 Environmental impact for multi-storey and attached building refurbishment

Multi-storey and attached building refurbishment cases are described in Table 29 and Table 30. Environmental impact calculations are made for 50 year building operation. The carbon footprint assessment results for multi storey- and attached building refurbishment to low-energy- and passive structure buildings are given in Table 31 and Table 32. Fossil energy results are given in Table 33 and Table 34 and non-renewable raw material consumption is shown in Table 35 and Table 36.

Table 29. Refurbishment cases for concrete multi-story building.

Structure	Low energy structures		Passive energy structures		
	Case M1	Case M2	Case M3	Case M4	Case new
Demolition	–	Outer concrete layer	–	Outer concrete layer	Existing building
Exterior wall	W1 (3 layer rendering façade)	W2 (100 mm concrete with tile façade)	W1 (3 layer rendering façade)	W2 (100 mm concrete with tile façade)	concrete element with tile facade
Base floor	B1 (EPS + parquet)	B1 (EPS + parquet)	B1 (EPS + parquet)	B1 (EPS + parquet)	(EPS + parquet)
Roof	R1 (asphalt mastics cover)	R1 (asphalt mastics cover)	R1 (asphalt mastics cover	R1 (asphalt mastics cover)	asphalt mastics cover
Window	Quadruple pane window	Quadruple pane window	Quadruple pane window	Quadruple pane window	Quadruple pane window

Table 30. Refurbishment cases for wooden frame attached building.

Structure	Low energy structures		Passive energy structures	
	Case A1	Case A2	Case A3	Case A4
Exterior wall	WA1	WA2	WA1	WA2
Base floor	BA1	BA1	BA1	BA1
Roof	RA1	RA2	RA1	RA2
Window	Quadruple pane window	Quadruple pane window	Quadruple pane window	Quadruple pane window

Table 31. Carbon footprint (kg CO_2 eq) for multi-storey building (operation period 50 years).

	Existing building, no renovations	Refurbishment into low energy building Case M1	Low energy building new construction Case M2	Refurbishment into passive structure Case M3	Refurbishment into passive structure Case M4	Passive structure building,new construction Case M New
Demolition			342		342	21 702
Exterior wall (W1/W2)		13 028	59 867	18 245	65 408	152 045
Base floor		8 735	8 735	8 735	8 735	41 273
Partition wall		0	0	0	0	86 832
Roof		16 650	16 650	21 314	21 314	45 024
Partition floor						107 566
Window		9 776	9 776	9 776	9 776	9 776
Transportation to the site		237	857	268	889	7 066
Heating	2 533 770	979 879	979 879	736 359	736 359	185 472
Electricity	915 327	606 095	606 095	612 279	612 279	612 279
Hot water	991 475	991 475	991 475	991 475	991 475	991 116
Total	**4 440 572**	**2 625 874**	**2 673 676**	**2 398 452**	**2 446 578**	**2 260 151**
Total/m^2	**2 400**	**1 419**	**1 445**	**1 296**	**1 322**	**1 222**

Table 32. Carbon footprint (kg CO_2 eq) for attached building type (operation period 50 years).

	Existing building, no renovations	Refurbishment into low energy building Case A1	Low energy building new construction Case A2	Refurbishment into passive structure Case A3	Refurbishment into passive structure Case A4	Passive structure building, new construction Case A New
Demolition		not considered	not considered	not considered	not considered	not considered
Exterior wall		2 950	11 656	4 916	13 907	6 209
Base floor		6 737	6 737	6 737	6 737	31 915
Partition wall		0	0	0	0	4 315
Roof		34 643	11 737	42 016	17 132	44 343
Partition floor		not exists	not exists	not exists	not exists	not exists
Window		9 776	9 776	9 776	9 776	9 776
Transportation to the site		254	300	289	354	3 663
Heating	1 319 976	450 765	450 765	355 509	355 509	153 090
Electricity	203 213	150 595	150 595	148 781	148 781	170 554
Hot water	290 871	290 871	290 871	290 871	290 871	290 871
Total	**1 814 060**	**946 592**	**932 437**	**858 895**	**843 067**	**714 736**
Total/m^2	**3 359**	**1 753**	**1 727**	**1 591**	**1 561**	**1 324**

Table 33. Fossil energy (MJ) for multi-storey building (operation period 50 years).

	Existing building, no renovations	Refurbishment into low energy building, case M1	Low energy building new construction, case M2	Refurbishment into passive structure, case M3	Refurbishment into passive structure, case M4	Passive structure building, new construction, case M New
Demolition			4 795		4 795	301 180
Exterior wall		115 958	448 095	183 385	519 699	1 195 456
Base floor		195 609	195 609	195 609	195 609	468 021
Partition wall		0	0	0	0	691 200
Roof		215 627	215 627	274 502	274 502	434 342
Partition floor						819 920
Window		158 431	158 431	158 431	158 431	158 431
Transportation to the site		4 924	17 828	5 570	18 495	146 946
Heating	37 403 267	14 464 879	14 464 879	10 870 057	10 870 057	2 737 920
Electricity	15 936 492	10 552 542	10 552 542	10 660 221	10 660 221	10 660 221
Hot water	14 636 061	14 636 061	14 636 061	14 636 061	14 636 061	14 630 760
Total	**67 975 820**	**40 344 032**	**40 693 867**	**36 983 836**	**37 337 870**	**32 244 396**
Total/m^2	**36 744**	**21 808**	**21 997**	**19 991**	**20 183**	**17 429**

Table 34. Fossil energy (MJ) for attached building type (operation period 50 years).

	Existing building, no renovations	Refurbishment into low energy building Case A1	Low energy building new construction Case A2	Refurbishment into passive structure Case A3	Refurbishment into passive structure Case A4	Passive structure building, new construction Case A New
Demolition		not considered	not considered	not considered	not considered	not considered
Exterior wall		39 725	166 382	65 690	198 919	89 536
Base floor		93 015	93 525	93 015	93 015	512 877
Partition wall		0	0	0	0	18 945
Roof		336 954	163 897	424 169	241 890	470 116
Partition floor		not exists	not exists	not exists	not exists	not exists
Window		158 431	158 431	158 431	158 431	158 431
Transportation to the site		5 255	6 206	5 982	7 317	62 833
Heating	19 485 360	6 654 150	6 654 150	5 247 990	5 247 990	2 259 900
Electricity	3 538 080	2 621 970	2 621 970	2 590 380	2 590 380	2 969 460
Hot water	4 293 810	4 293 810	4 293 810	4 293 810	4 293 810	4 293 810
Total	**27 317 250**	**14 203 309**	**14 158 370**	**12 879 467**	**12 831 752**	**10 835 907**
Total/m^2	**50 588**	**26 302**	**26 219**	**23 851**	**23 763**	**20 066**

Table 35. Non-renewable raw-material (kg) for multi-storey building (operation period 50 years).

	Existing building, no renovations	Refurbishment into low energy building, case M1	Low energy building new construction, case M2	Refurbishment into passive structure, case M3	Refurbishment into passive structure, case M4	Passive structure building, new construction, case New
Demolition			36		36	2 251
Exterior wall		65 848	235 859	75 080	245 663	580 710
Base floor		6 138	6 138	6 138	6 138	466 664
Partition wall		0	0	0	0	429 408
Roof		31 273	31 273	39 334	39 334	180 526
Partition floor						574 240
Window		8 264	8 264	8 264	8 264	8 264
Transportation to the site		75	312	87	324	2 685
Heating	1 242 754	480 607	480 607	361 166	361 166	90 970
Electricity	445 405	294 930	294 930	297 940	297 940	297 940
Hot water	486 295	486 295	486 295	486 295	486 295	486 119
Total	**2 174 453**	**1 373 430**	**1 543 713**	**1 274 304**	**1 445 160**	**3 119 776**
Total/m^2	**1 175**	**742**	**834**	**689**	**781**	**1 686**

Table 36. Non-renewable raw-material (kg) for attached building type (operation period 50 years).

	Existing building, no renovations	Refurbishment into low energy building Case A1	Low energy building new construction Case A2	Refurbishment into passive structure Case A3	Refurbishment into passive structure Case A4	Passive structure building, new construction Case A New
Demolition		not considered	not considered	not considered	not considered	not considered
Exterior wall		4 526	52 988	7 762	56 647	10 916
Base floor		7 089	7 089	7 089	7 089	442 917
Partition wall		0	0	0	0	3 404
Roof		63 370	22 800	76 359	33 566	81 686
Partition floor		not exists	not exists	not exists	not exists	not exists
Window		8 264	8 264	8 264	8 264	8 264
Transportation to the site		81	98	94	119	1 139
Heating	647 417	82 596	82 596	47 555	47 555	75 087
Electricity	98 885	73 281	73 281	72 398	72 398	82 993
Hot water	142 665	142 665	142 665	142 665	142 665	142 665
Total	**888 967**	**381 872**	**389 781**	**362 187**	**368 304**	**849 071**
Total/m^2	**1 646**	**707**	**722**	**671**	**682**	**1 572**

6.8 Discussion

6.8.1 Raw-material consumption in building refurbishment

Use of natural resources in building refurbishment and operation phase has an impact to the environment. The impact magnitude depends not only on the insulation but also on the refurbishment case, energy efficiency target, façade materials and roof materials but also on the use of energy raw-materials needed for building operation.

In the case of concrete multi-storey building refurbishment, the total non-renewable raw- material saving compared to the existing building and 50 years' operation was in maximum 40% (600–900 tons) (Figure 45). In the case of attached wooden building refurbishment, the total non-renewable raw material saving compared to the existing building and operation of 50 years was a little bit higher, in maximum 45% (360–400 tons) (Figure 46).

When the refurbishment case is massive (total concrete multi-storey building demolition and new passive building construction, M New), then fossil raw-material consumption (refurbishment and 50 year operation) shows no savings compared to the existing building with no refurbishment. Compared to the lighter refurbishment cases (M1–M4) and 50 year operation, the massive refurbishment case (demolition and new construction) shows even 2.4 times (MNew/M3) more non-renewable raw-materials than lighter refurbishment cases.

Also attached lightweight wooden building refurbishment cases are beneficial in terms on non-renewable raw-material consumption when the refurbishment cases are lighter (A1–A4) but when the case is total demolition and new construction then the non-renewable raw-material consumption was 1.7 times higher than in the lighter refurbishment case (ANew/A3). Comparison with existing building with no renovation and operation 50 year shows that also massive refurbishment has fossil raw-material saving effect, which was 40 tons (refurbishment and 50 year operation).

On the other hand, non-renewable raw-materials in existing building case (consider only operational energy) are very much fossil based whereas materials which are used in building refurbishment are mainly based on the consumption of mineral materials. As in raw material evaluations, fossil based materials are much more valuable than mineral materials, by having higher weighting coefficient, the main issue related to the non-renewable raw material consumption in refurbishment is energy consumption after refurbishment. It is important what type of non-renewable raw material is saved after refurbishment.

According to the results shown in Figure 47 and Figure 48 non-renewable material share in building refurbishment can be as high as 60–70% from the refurbishment and building operation of 50 years (refurbishment case is total demolition and new construction). When the refurbishment case is lighter and no total demolition is needed then the non-renewable material share during the 50 year operation time is 10–20%.

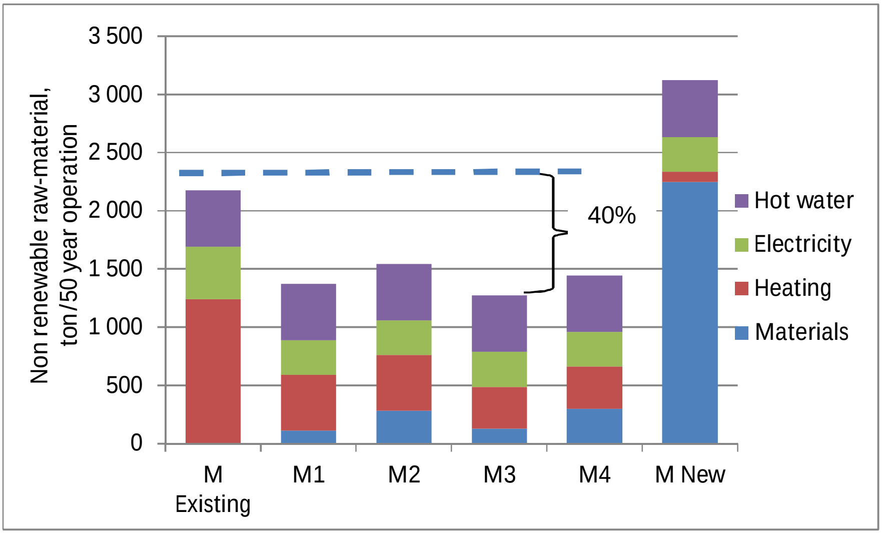


Figure 45. Non-renewable raw-material consumption for multi-storey buildings with operation period 50 year (M existing has no refurbishment, M1–M4 has light refurbishment and M new is the case for total demolition and new construction).

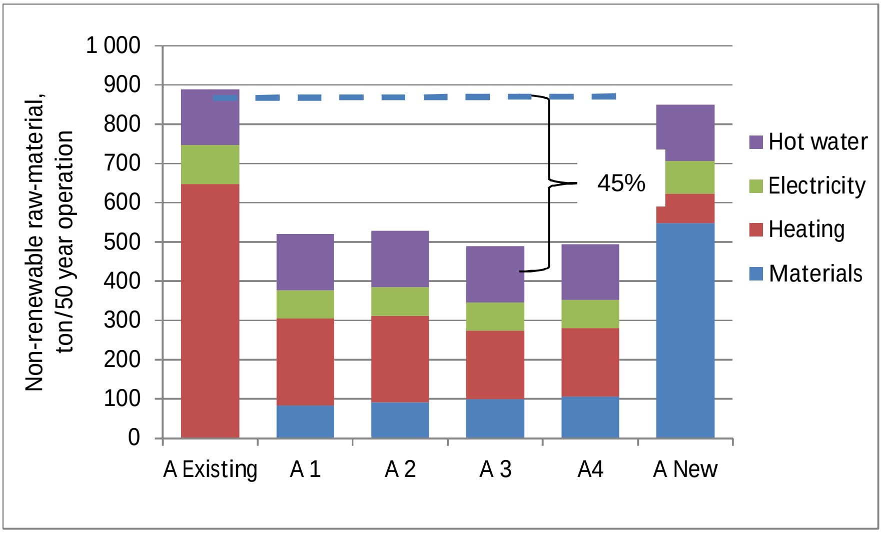


Figure 46. Non-renewable raw-material consumption for attached building with operation period 50 year (A existing has no refurbishment, A1–A4 has light refurbishment and A new is the case for new construction).

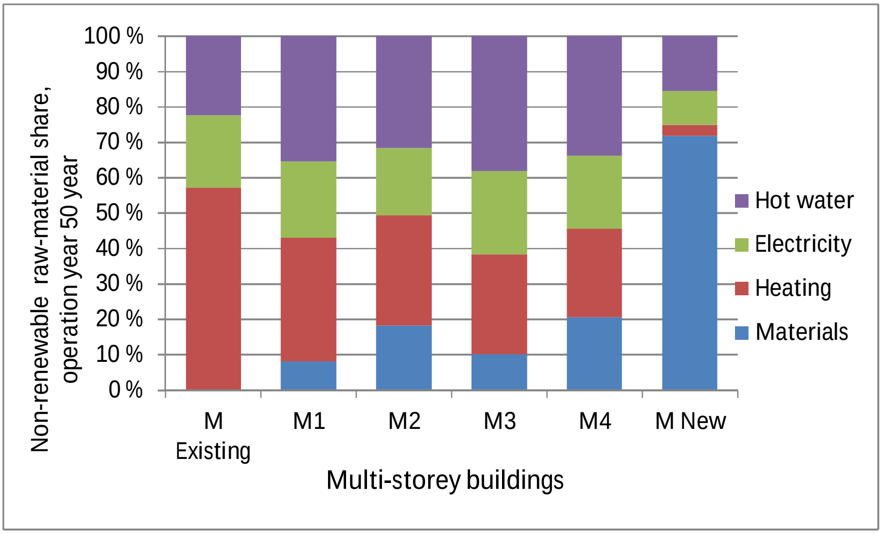


Figure 47. Non-renewable raw-material share from the 50 year multi-storey building operation (M existing has no refurbishment, M1–M4 has light refurbishment and M new is the case for total demolition and new construction).

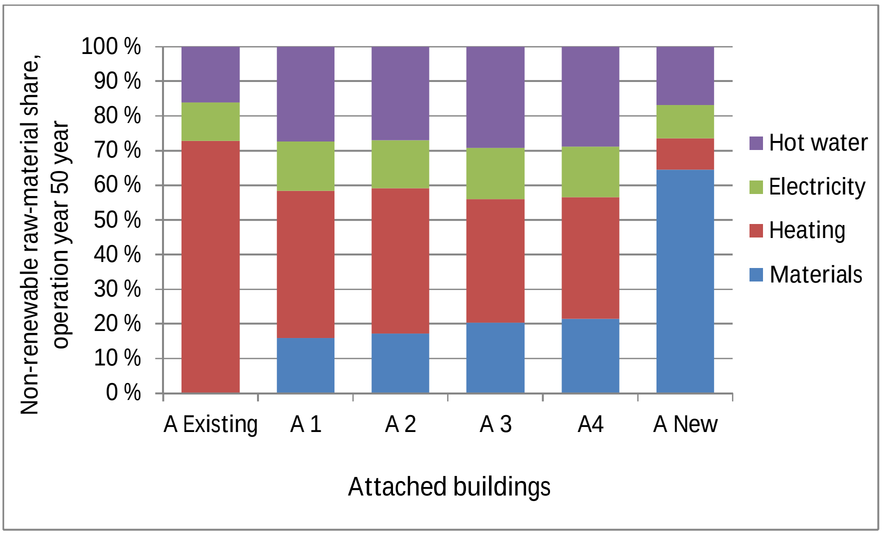


Figure 48. Non-renewable raw-material share from the 50 year attached building operation (A existing has no refurbishment, A1–A4 has light refurbishment and A new is the case for new construction.

6.8.2 Carbon footprint in building refurbishment

The assessment shows that the impact from the increase of material consumptions in the refurbishment into the level of low energy- and passive house structures is beneficial when carbon footprint is the criterion and the result is compared to the carbon footprint of corresponding non-refurbished building case.

Carbon footprint saving

According to the result carbon footprint saving achieved in typical multi-storey building refurbishment is ~1800–2200 tons/ 50 year operation (Figure 49) and in attached wooden building it is ~870–1100 tons/ 50 year operation *(*Figure 50*)*, when cases are compared to the non-refurbished options.

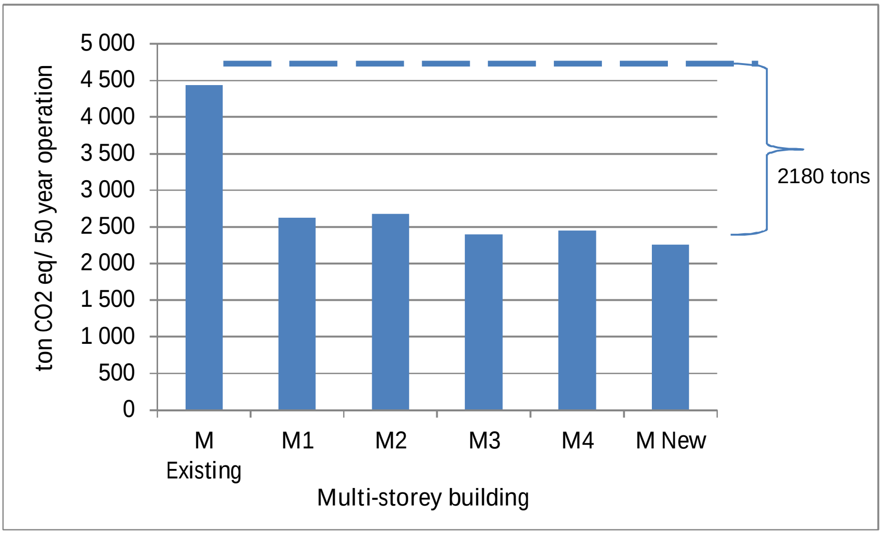


Figure 49. Carbon footprint for the 50 year multi-storey building operation (M existing has no refurbishment, M1–M4 has light refurbishment and M new is the case for total demolition and new construction).

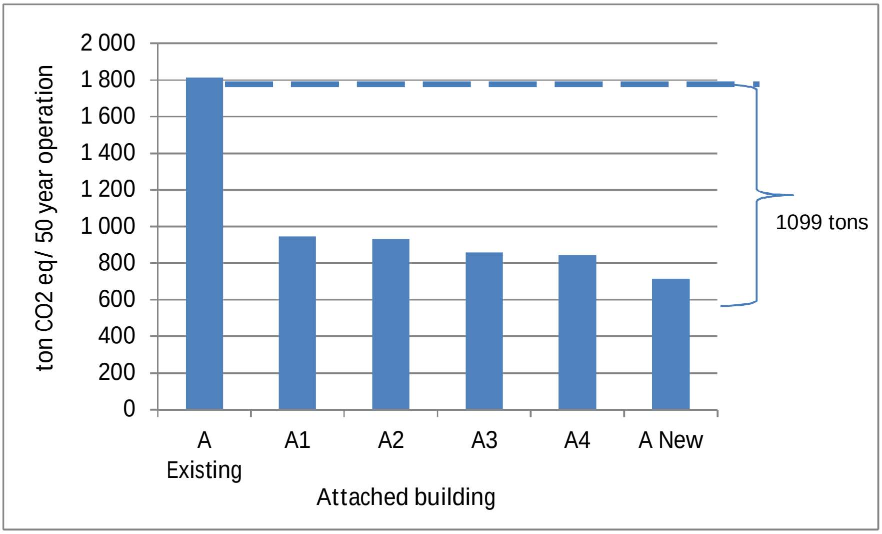


Figure 50. Carbon footprint for the 50 year attached building operation (A existing has no refurbishment, A1–A4 has light refurbishment and A new is the case for total demolition and new construction).

Payback time

For the multi-storey concrete building refurbishment cases the carbon footprint payback time is less than 2.5 years and for total demolition and new construction case it is less than 10 years, compared to the not refurbished existing concrete building case (Figure 51).

For the attached wooden frame building refurbishment cases carbon footprint payback time is less than 3 year and for total demolition and new construction it is less than 5 year compared to the not refurbished existing wooden building case (Figure 52).

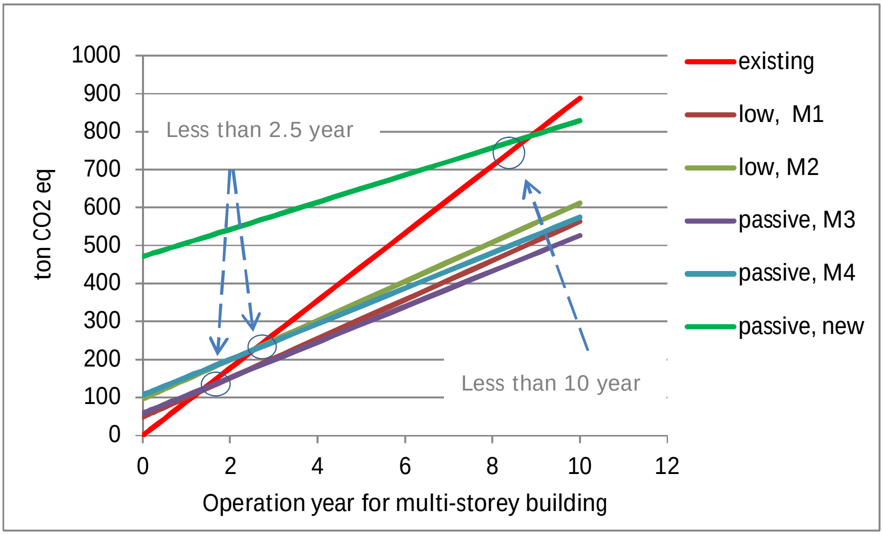


Figure 51. Carbon footprint for the multi-storey concrete building refurbishment.

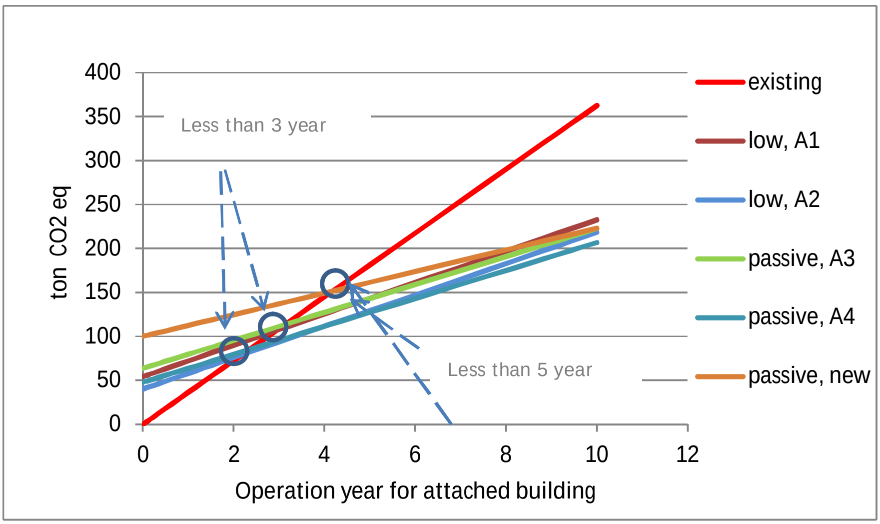


Figure 52. Carbon footprint for the attached wooden frame building refurbishment.

Carbon footprint share

As the refurbishment considers only additional envelope insulation and improvements in air tightness (M1–M4 and A1–A4), and no heat recovery or other HVAC related refurbishment was considered, the impact from the energy reduction was relatively small. In this assessment it was assumed that energy supply for heating is average district heat and electricity is average Finnish electricity. This assumption shows that carbon footprint from the materials used in refurbishment is small; the share is less than 10%, whereas operational energy share is more than 90% during 50 year operation. But when the refurbishment case is demolition and new construction (M new and A new), carbon footprint from the refurbishment materials reach to 20% when the comparison is made for the 50 year building operation (Figure 53 and Figure 54).

On the other hand electricity and hot water consumption are very much user dependent. When carbon footprint from the materials used in refurbishment is compared with the 50 year heating, material share can reach up to 70% in the refurbishment case demolition and new construction (Figure 55).

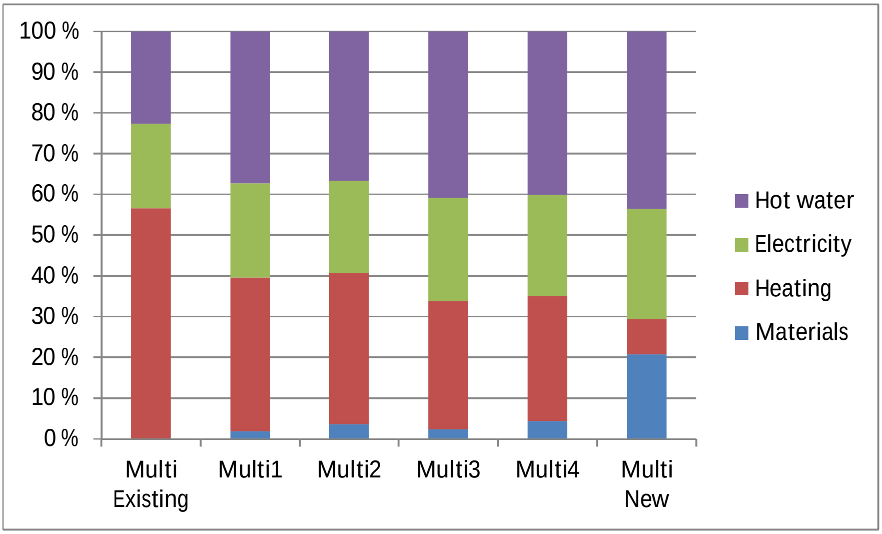


Figure 53. Carbon footprint share from refurbishment materials, heating, hot water and electricity use during 50 year multi-storey building operation (M existing has no refurbishment, M1–M4 has light refurbishment and M new is the case for total demolition and new construction).

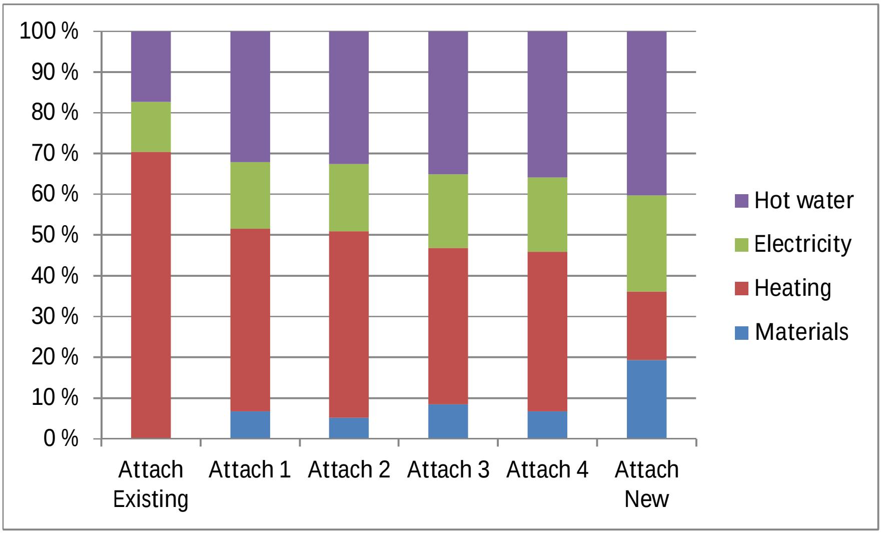


Figure 54. Carbon footprint share from refurbishment materials, heating, hot water and electricity use during 50 year attached building operation (A existing has no refurbishment, A1–A4 has light refurbishment and A new is the case for new construction.

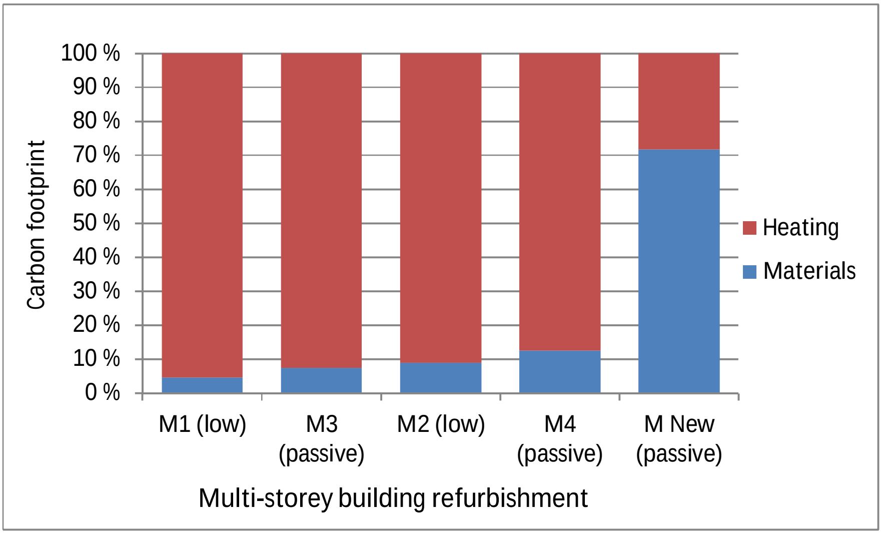


Figure 55. Carbon footprint share from refurbishment materials and heating during 50 year multi-storey building operation (M1–M4 has light refurbishment and M new is the case for demolition and new construction).

6.8.3 Renovation into low and passive energy building structures

Figure 56 and Figure 57 show the fossil energy from the use of refurbishment materials for multi-storey and attach building renovations. According to the studied cases the fossil energy embodied to the refurbishment materials is dependent from renovation concept and used material types. Embodied fossil energy can be less in the refurbishment to the passive envelope than in the low energy case (817 GJ < 1040 GJ) when the refurbishment to passive level is done as additional external insulation with rendering façade and low energy case is done with as external concrete and insulation replacement.

In attached buildings main issues for embodied fossil energy are the use of concrete roof tiles and masonry façade versus wooden façade and asphalt mastics roof.

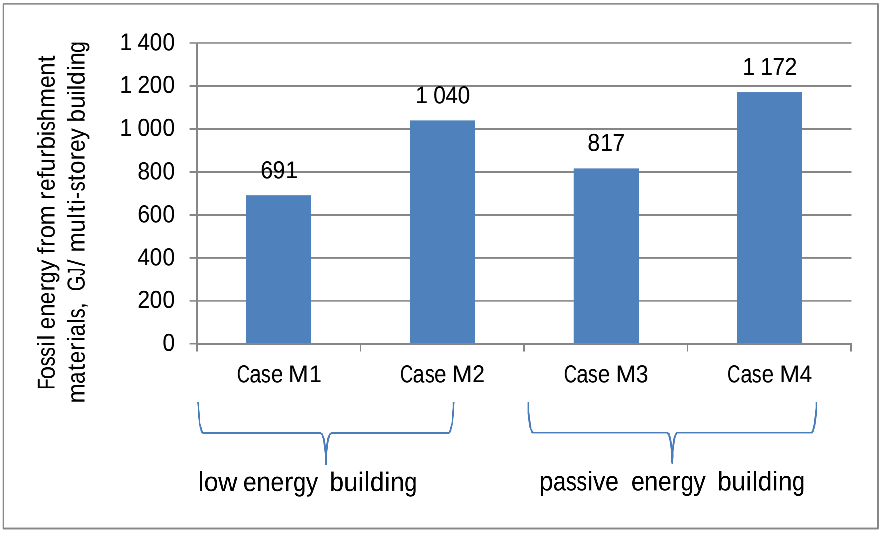


Figure 56. Fossil energy from the use of building materials in multi-storey concrete building refurbishment and partial wall demolition (Case M2 and M4 external wall layer demolition).

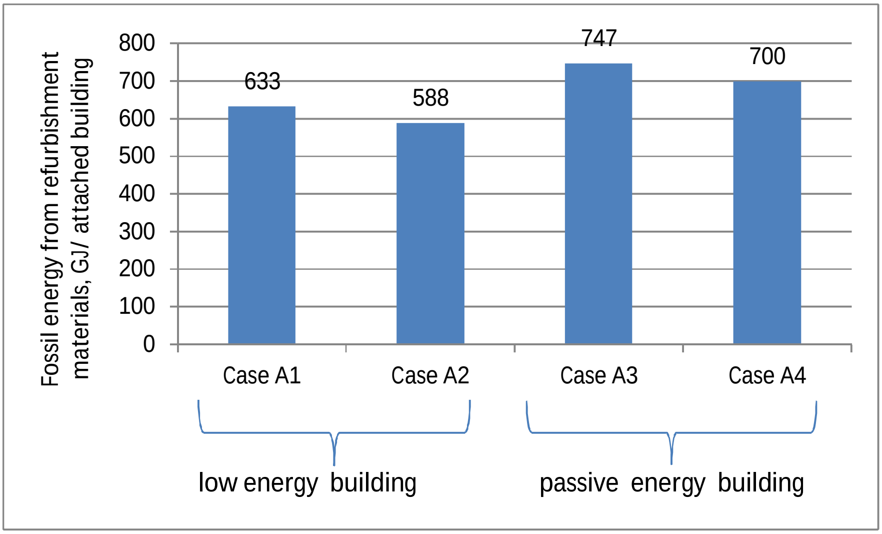


Figure 57. Fossil energy from the use of building materials in wooden attached building refurbishment.

On the other hand, refurbishment to the level of low- or passive energy building structures reduces operational energy and environmental impact. Carbon footprint reduction in the multi-storey building refurbishment cases is 39–48% compared to the existing building with no refurbishment (operation period 50 year) (*Figure 58*). And carbon footprint reduction in attached building refurbishment cases is 46–54% compared to the existing building with no refurbishment (operation period 50 year) (Figure 59).

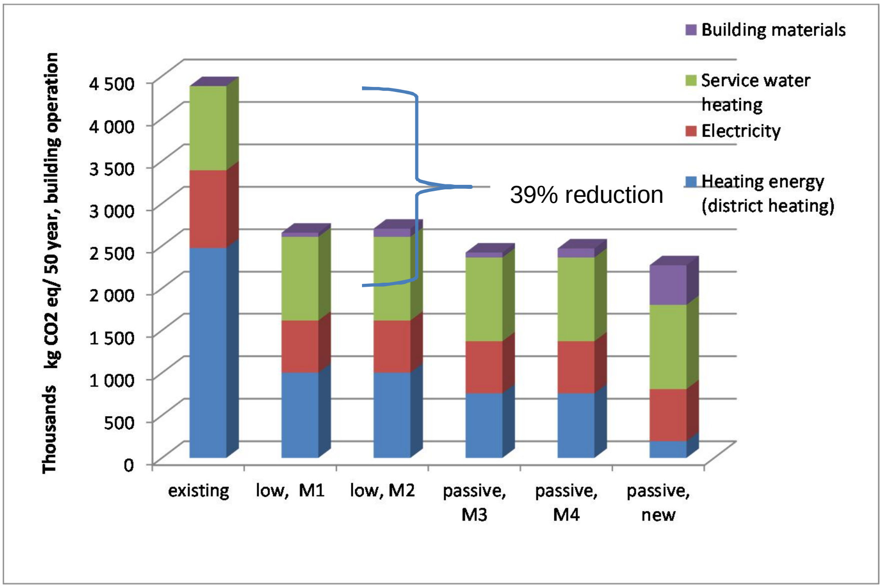


Figure 58. Carbon footprint for existing multi-storey building and for refurbished cases (operation period 50 year).

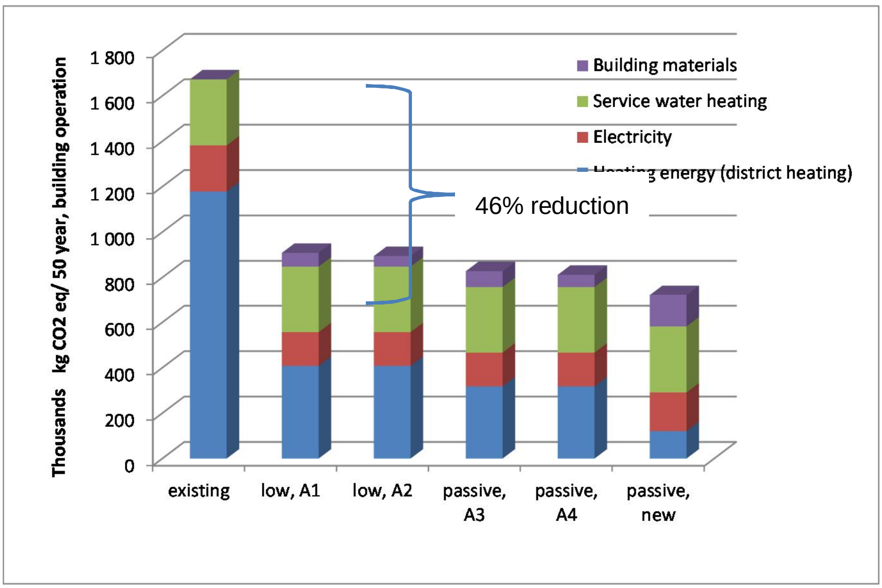


Figure 59. Carbon footprint for existing attached building and for refurbished cases (operation period 50 year).

6.8.4 Operational energy type

Material impact from the building renovation and operation depends also very much from the operational energy type. In this study average Finnish district heat and electricity were used but it should be noted that when the operational energy is produced in another way the renovation material significance is totally different compared to the operational energy.

For example when bio-based heat is used then carbon footprint value for heat is almost zero and when electricity is produced by hydro or solar energy then also impact from electricity use remains almost zero. In these cases renovation material type and renovation method is much more significant with respect of environmental impact than operational energy during building use.

6.9 Conclusions

The effect of refurbishment on the environmental point of view depend on:

- energy efficiency target level (low energy/passive house)
- insulation material type used in refurbishment (natural, waste material, oil based, mineral based)
- façade material type (concrete, stone, brick, wood)
- roof covering material type (asphalt based, roofing tile, steel)
- energy distribution system and type (gas, oil, electricity, wind, ground source pump, solar).

When the refurbishment goal is energy efficiency (low energy buildings, passive houses, ZEB level…) more insulation is needed which causes also more impact from material use but less impact from operational energy; vice a verse – when there is no big ambitions to lower operational energy content after refurbishment – then more environmental impact is caused from energy use and less form material use.

In this assessment building refurbishments results in the significant decrease in carbon footprint and it was achieved with relatively low material consumption. From the view point of GHGs, it is worthwhile to refurbish all poorly insulated buildings as soon as possible because of the considerable high annual energy demand and emissions.

For multi-story and attached building refurbishment cases carbon footprint payback time was considerably low, less than 3 years, but when the refurbishment is massive, like demolition and new construction, then the payback time varied between building types.

When the criterion is carbon footprint payback time, the respectable refurbishment case for attached building, besides with additional insulation, is also demolishing case with new building construction (as the payback time was also low for this massive refurbishment case, it was less than 5 year). For multi-storey building, the preferable refurbishment method is additional insulation, because the carbon footprint payback time for massive refurbishment case was high (twice as high as in the case of attached wooden building).

The different factors are related to the material significance assessment. You cannot assess the heat demand without the knowledge of the electricity and the use of materials (insulation) effect. However, on the bases of chosen scenarios, the significance of materials in new building is bigger than that of heating spaces.

Passive buildings are very complex issues and when refurbishment considers only envelope insulation then environmental impact from the used materials remain low. On the other hand when after refurbishment all passive building criteria are met then used materials have significant impact on the carbon footprint compared to the operational energy. This will be the case also in the near future, because energy production industry agreed to reduce carbon emissions 20% by 2020 and 80% by 2050, which means that during building operation impact from energy use is not so substantial any more than used material types.

7. Economical analyses

This chapter describes principals of economical analyses which can be utilized in sustainable renovations and which were also applied in the analysis of Mecoren concepts (Passive level envelope, ventilation renovation, replacing renovation with solar collectors). In addition, this Chapter also gives recommendations for the selection of concepts on the basis of the analyses.

7.1 Introduction

Economic analyses may be drawn up in early stages of renovation design. Figure 60 outlines the possibilities to utilise life-cycle based decision making for example when comparing alternative energy saving solutions and when analysing cost-effectiveness, profit and cash flows.

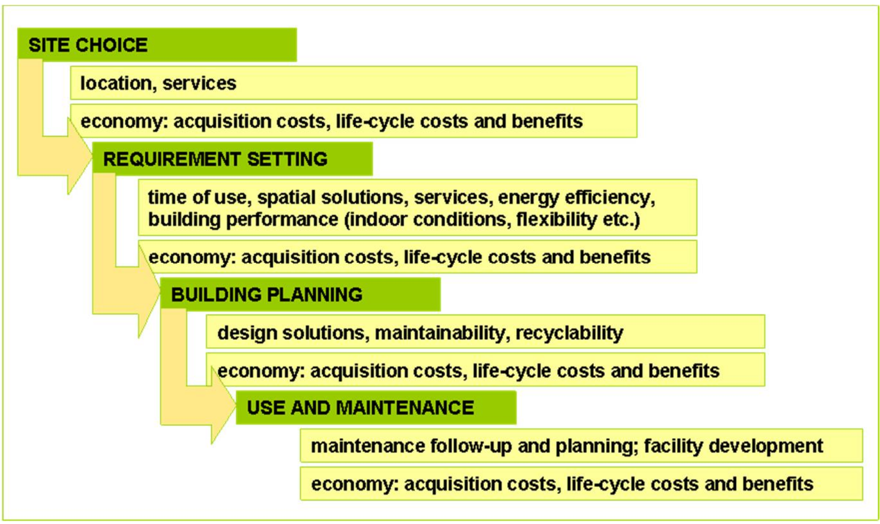


Figure 60. Main phases and possible objects of life-cycle economic decision making.

The economic analyses of sustainable renovation are directly integrated to sustainable renovation processes (Figure 61) as demands for economic selection of renovation actions and budgeting increase.

The objects of an analysis may be set on the level of

- building parts or systems (for example refurbishment or replacing of facades, windows or ventilation)
- building (extensive renovation)
- building stock (for example extensive renovation of apartment houses from 1960 and 1970).

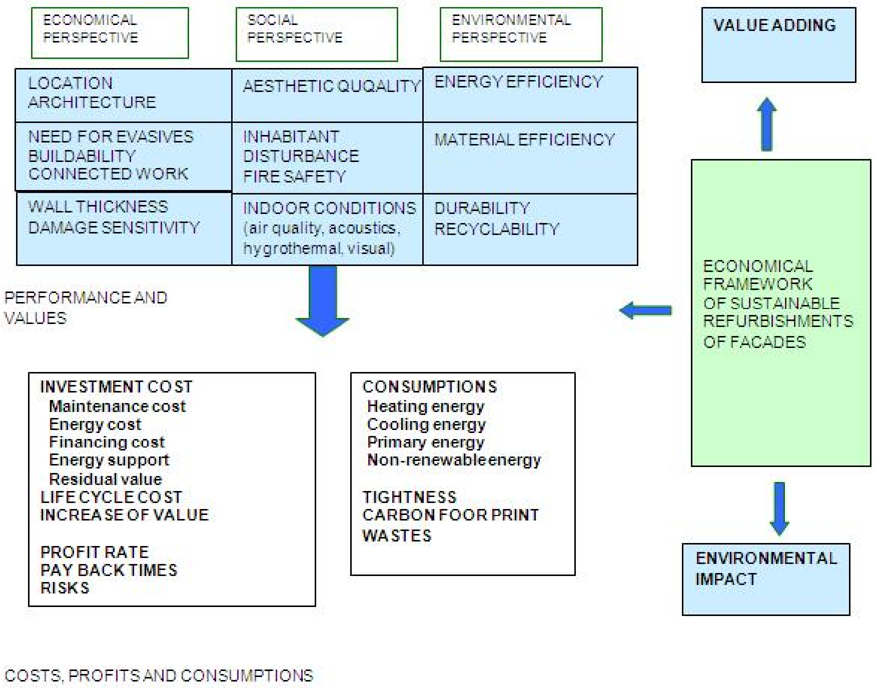


Figure 61. Assessment framework of sustainable extensive renovations.

Many experiences of sustainable renovations show that it is both technically and economically possible to renovate also quite old buildings even so thoroughly that they may be described as passive houses after renovation. Then the key strategies of extensive renovation are

- good planning and construction
- very good insulation and air-tightness of building envelope
- new energy saving windows
- mechanical ventilation system with efficient heat recovery

– change of electrical or oil heating to district heating or using renewable energy resources.

Extensive sustainable renovation is typically a result of a long-term preparation. Then the acceptability of total costs is compared with rent potential, value of facility and possible savings in energy consumptions and carbon footprints. The older the building is the more important reference it is for itself. It is important to identify the aesthetics of the building and make use of similar materials and solutions as was used originally.

The phases and issues of decision making in case of extensive sustainable renovation have been collected to the following table.

Table 37. Phases of sustainable renovation and issues of decision making.

<table>
<tr><td colspan="5">SUSTAINABLE RENOVATION ISSUES</td></tr>
<tr><td>Solution-oriented investment process</td><td colspan="3">Principles of implementation solutions</td><td>Goal-oriented maintenance and use</td></tr>
<tr><td rowspan="2">Project preparation and determination of implementation method

Comprehensive planning coordinated by contractor that includes early-stage networking and interactivity

Preparation and implementation of sustainable purchases (structural engineering, building services engineering)

Interactive and quality assured building

Consideration on users' behaviour and development of new kind of rental agreements</td><td>Architecture</td><td>Structural engineering</td><td>Building services</td><td rowspan="2">Maintenance and user service purchases that meet sustainability criteria

Handover inspection

Ascertaining building service settings and support for needs oriented use</td></tr>
<tr><td>Integration with regional objectives (areal planning, energy production and portfolio management)

Lay-out, extensibility of the building

Adequate life cycle

Façade compatible with cultural values

Facade with adequate protection that makes use of natural light

Main material selections</td><td>Better envelope insulation level; thickness control with insulation selections

Most energy efficient windows available by competitive bidding

Excellent sealing

Sun protection

Material efficiency

Management of building physical behaviour

Durable structures that can be cleaned, repaired and recycled

Eco-labels and emission classifications</td><td>Increased share of renewable energies

Needs based (integrated), adaptable and recyclable building services, efficient heat recovery

Minimisation of excess capacity and transmission losses

Ensuring the possibilities of external air and free cooling

Energy efficient lighting

Energy efficient pumps and electrical devices

Adaptable electrical and technical installation routes

Water supply system that prevents unnecessary consumption</td></tr>
<tr><td>Adequate life cycle, low risk of damage</td><td>Ambient conditions compliant with requirements</td><td>Optimal energy efficiency</td><td colspan="2">Low primary energy, small carbon footprint</td></tr>
<tr><td colspan="5">reasonable building costs – lower facility costs – higher market values – better utility values</td></tr>
</table>

Sustainable facility business is based on systematic target setting, planning and steering of construction, possible user surveys as well as continuous control of energy consumptions and indoor climate.

Other economic matters may concern possibilities to extra construction, investment supports and tax advantages.

The analysed renovation concepts are as follows:

- Ventilation renovation with effective heat recovery
- Passive level envelope covering replacing of facades, windows and additional thermal insulation of base and upper floors; for example extra insulation by mineral wool integrated to replacing renovation +300 mm compared to current situation U-value 0,40 → 0,17 $W/m^2/K$). The U -values of windows can be improved form 2.8 to 0.8 $W/m^2/K$, base floors 0.35 to 0.12 $W/m^2/K$ and roofs 0,30 to 0,08 $W/m^2/K$.
- Extensive renovation with solar collectors covering passive level envelope and renewing of ventilation.

7.2 Management of sustainable renovation

Sustainable renovation is usually prepared with long-sighted perspective and with possible targets of repairing damages, technical aging, unsatisfied indoor climate, and changing space divisions. Also demolitions of worst buildings increase. Renovation actions don't usually cover all building parts and whole building which means that technical characteristics of non-repaired parts don't change. Improving energy efficiency and indoor climate means renewing HVAC systems. It is necessary to be able to understand and integrate economical and performance-based actions and identify potential for new technical solutions.

The process of improving the energy efficiency of the built environment begins with land use planning.

Where in-house experience with innovative construction procurement is limited, it is strongly advisable to contract an external consultant to advise or manage the process from the beginning.

In the case of extensive renovation it is necessary to define alternative solutions on the basis of which it is possible to choose the most economical combination. The reasonableness of renovation costs are compared to both changes in value of facility, residual time of use, possible rent potential and changes in energy consumptions, and assessed primary energy consumption and carbon foot print. Also the possibilities for additional construction may be an activated economical factor as shown in Figure 62.

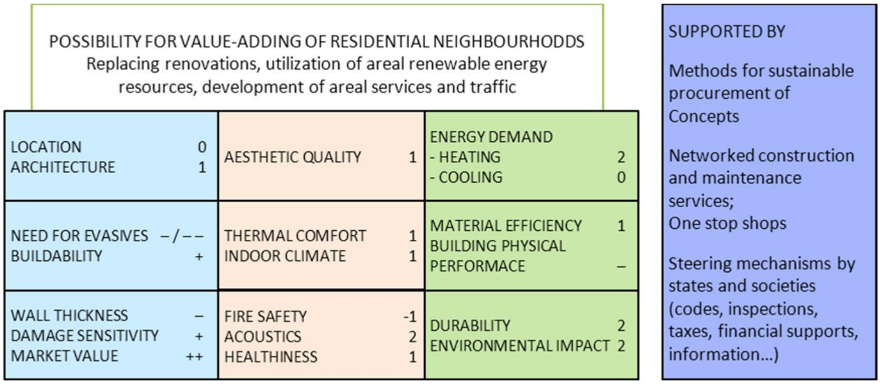


Figure 62. Total effects of replacing renovations on performance and values (2 = significant improvement, 1 = minor improvement, 0 = no change, -1 = minor worsening, -2 = significant worsening).

It is important to establish clear baseline information on energy consumption at the beginning of the planning stage, together with other aspects such as material flow and chemical use analysis. Where information and expertise is not available in house, baseline data collection should be contracted out to expert consultants/auditors.

At renovation planning stage, a suitable model for life cycle costing (LCC) should be identified align with the principles of ISO 15686-5 standard or equivalent, to inform decisions throughout the procurement process. Facility managers should be involved at this stage.

The suitability of individual project for external public financing should be assessed with reference to their investment characteristics, and potential financing options evaluated on the basis of their impact on sustainability.

Contractors which are responsible for design and construction works must cooperate closely on the project. Designers' responsibility should not end once the final design is agreed. Combined design and build contracts are often preferable or models in which architects remain involved in the supervision and assessment of the construction work.

Also possible risks should be assessed and documented for risk management in use phase.

All tenders should be awarded on a range of quality criteria and not just lowest price. If new technical solutions during market consultation activities have been identified, they must be highlighted within the design concept during tendering for design work.

In tendering for construction works, quantitative performance based specifications (such as the maximum of primary energy requirement in MJ/year for heating) are recommended, based on the final design. Additional points may be awarded for contractors offering even better performance to access the full potential of the supply chain. Also quality management measures (such as blower door tests) must be considered.

Depending on the contractual model followed either the designer or construction company should be obliged to provide training to facility managers and relevant users on how to maintain the building, and operate any new innovative solutions. Bidders may be asked to describe training methods in their tender applications.

7.3 Economic analysis methods

The Directive on the energy performance of buildings (recast) constitutes that cost-optimal methodology framework can create a legal framework for raising Member States' minimum energy performance requirement levels to ensure that all economically rational measures are implemented. The European Commission has established a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for new buildings and building elements. Economic analyses within Mecoren project are based on cost-optimal methodology meaning calculation of life cycle costs of traditional and combined renovation measures.

According to ISO 15686-5 [2008] Life Cycle Costing (LCC) is a technique for estimating the cost of whole buildings, systems and/or building components and materials, and for monitoring the occurred throughout the lifecycle. The application of LCC methodology is based on systematic analysis process [Langdon 2007, 2010] as shown in Figure 63.

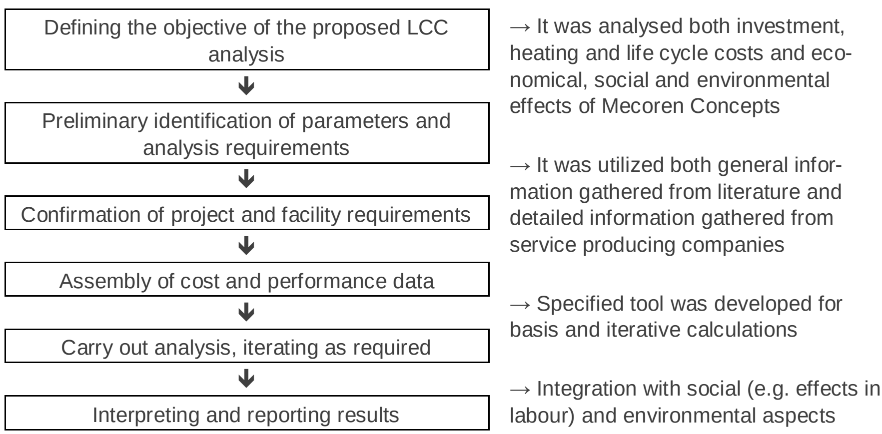


Figure 63. Application of the economical methodology [ISO 15686-5 2008].

The results of economic analysis is usually presented in terms of net present value. This is calculated by summing up the activated costs in different years for present with present unit costs. The energy costs are calculated considering the realistic increase of costs. The cost factors of life cycle costs are presented in the following table.

Because of the predictive nature of life cycle costing methods, sensitivity analyses are often important in the connection of life cycle economics. Sensitivity analysis may be based on classification including for example the following three steps: basic – pessimistic – optimistic.

Table 38. Life Cycle Cost factors used in potential estimation [Langdon 2007, 2010].

Type of life-cycle cost	Description
Acquisition cost	Costs including all material, labour and sub costs caused by construction
Financial cost	Price of money. Real rate (nominal rate - inflation) is based on real need and price of money
Energy cost	Continual cost caused by the operation of the building including heating energy

The present value methodology means summing up of activated costs in different years for present either with present unit costs or taking the foreseen realized costs (usually energy cost) in account. Profit rate is usually specified by equation: savings in life-cycle costs/invested capital. Payback time is specified by equation: increase in acquisition cost/savings in life-cycle costs. The principles of economic analysis to be presented for stakeholders are presented in Table 38.

Table 39. General principles of life cycle analysis.

Challenge	Management
Understanding the demands of national energy renovation codes	Energy savings is not only an investment but also a demand by building codes to consider in connection to extensive renovation.
Assessment of extra costs caused by energy efficiency	Energy renovation usually becomes economical when it is integrated with other necessary renovation.
Definition of calculation period	Definition the basis of choice of calculation period (for example funding time) Real rise of energy prices: 0%/y, 2%/y, 4%/y, 8%/y (oil)
Matters to be taken in account for decision support	Effects to be shown clearly: social (such as improved and adjustable indoor circumstances including acoustics environmental (such as improved energy efficiency and smaller carbon foot print) economical (such as higher value of departments)

Extra cost of energy-efficiency compared to ordinary renovation vary from +10% to +50% being based on contents of renovation concepts, needs for additional planning, local conditions and needs for additional works.

MECOREN calculations used solid additional costs of energy efficiency as presented in Table 39.

Table 40. Unit costs applied within Mecoren calculations [SFS-EN 15459 2008, RIL 249-2009 2009].

Cost factor	Description	Acquisition cost summary	Calculative cost difference in energy-efficiency
Refurbishment of facades	Necessary cleaning, patching and covering according to condition survey	70 €/facade-m^2	
Thermo plastering of facades by extra insulation of 100 mm mineral wool	Is carried out over the old structure.	95 €/facade-m^2	+ 25 €/facade-m^2
Replacing of facade by new structure with extra insulation of 300 mm mineral wool	Demolition of old facade, smoothing and covering of underlay. Extra insulation of 300 mm.	300 €/facade-m^2, of which demolition and smoothing 150 €/facade-m^2	+230 €/facade-m^2
Replacing of windows	Choice of energy efficient windows (0,80 W/m^2K) in situation of necessary replacing of old structures	500 €/window-m^2	+250 €/window-m^2
Refurbishment and extra insulation of upper walls	Refurbishment of upper walls connected to conditioning survey and façade refurbishment	130 €/roof-m^2	+25 €/roof-m^2
Installation of ventilation in connection to pipeline operations	Installation of mechanical ventilation with adjustable air flows and high efficiency (over 80%) of heat recovery.	In connection to pipeline operations: 150 €/room-m^2 As independent work: 200 €/room-m^2	In connection to pipeline operations + 75 €/room-m^2 As independent work: +100 €/room-m^2
Solar heating			+ 3 €/kWh
Pipeline operations	Pipeline works all together	400 €/room-m^2	
Indirect costs	Extra costs of planning, control and general works on site		10% compared to acquisition costs
Investment support			Has been taken in account in analysis of building stock (19% of extra investment cost)
Financing cost	The financing cost caused by investment in energy efficiency		About 25% in relation to annual capital cost
Resale value	The value of building parts at the end of life cycle		About 25% in relation to total costs caused by additional thermal insulation

Cost factor	Description	Acquisition cost summary	Calculative cost difference in energy-efficiency
Energy charges	Basic heating energy charge (10/2011)	55 €/MWh	
	Heating energy price in average within 20 years (real rise of energy price + 4%/v)	103 €/MWh	
	Basic electricity energy price (10/2011)	80 €/MWh	
	Eletcricity energy price in average within 20 years (real rise of energy price + 4%/v)	150 €/MWh	

7.4 Recommendations and examples of economical analysis

This Section presents how to calculate life cycle costs of energy renovations and shows the importance of selected renovation concepts through example studies of economical analysis. The case studies are as follows:

- Refurbishment of day nursery Saana (located in Helsinki) in relation to energy saving
- Refurbishment of apartment house Vuorikatu 22 (located in Helsinki) in relation to energy saving

7.4.1 Day nursery

Day nursery Saana was taken in use in 1963 and it is in need for extensive renovation. The energy consumption was calculated and economic analysis was carried out for two concepts

- Basic energy renovation covering extra insulation (by 100 mm mineral wool) and improvement of tightness (n50: 4.0 → 2.0 /h) and heat recovery of ventilation
- Maximal energy renovation covering extra insulation, change of windows (U: 2.8 → 0.70 W/m^{2}K), improvement of tightness and heat recovery of ventilation.

The calculation results (in the following Table 41 and Figure 64) show that the energy renovation is also economically justified. The possible financial costs or supports to energy investments have not been included to the analysis.

Table 41. Economical analysis of energy renovation of Day nursery Saana.

Helsinki		Saana		
Total room-area		1 194 room-m^2	Basic energy renovation	Maximal energy reno-vation
Change in heating energy consumption		MWh/a	-115	-190
1. ACQUISITION COST				
Refurbishment of facades	457 m^2	€	15 000	15 000
Refurbishment of roof	1 130 m^2	€	25 000	25 000
Renewing of windows	137 m^2	€		21 000
Improvement of air-tightness		€	15 000	15 000
Improvement of heat recovery of venti-lation		€	8 000	15 000
Indirect costs		€	7 000	9 000
TOTAL		€	70 000	100 000
TOTAL		€/room-m^2	70	100
2. LIFE CYCLE COST IN 20 YEARS				
Acquisition cost		€	70 000	100 000
Resale value		€	-10 000	-10 000
Financial cost		€	18 000	25 000
Heating cost (real rise of energy price + 4%/a)		€	-118 000	-196 000
TOTAL		€	-40 000	-81 000
3. PAYBACK TIME		y	15	14

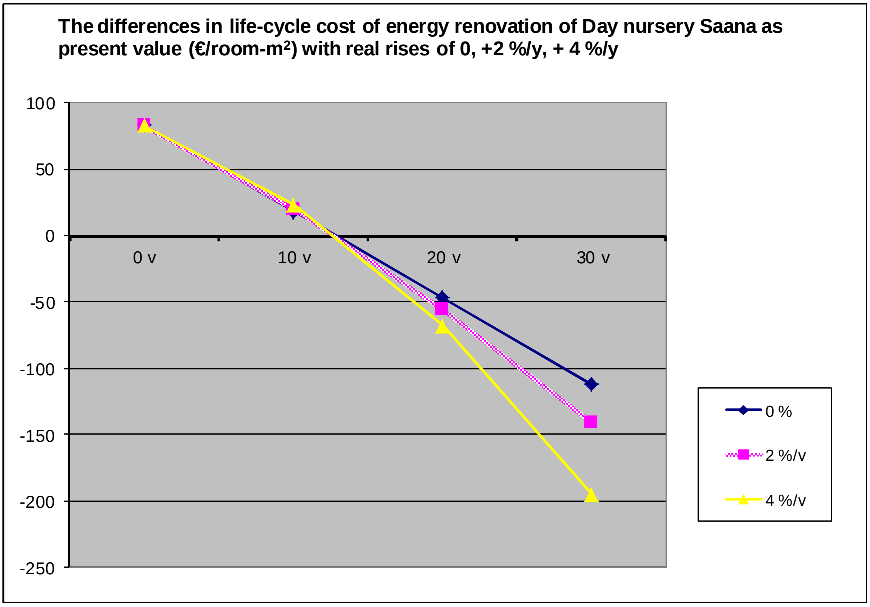


Figure 64. The importance of energy renovation of Day nursery Saana in time.

7.4.2 Apartment house

Renovation of Apartment house (Vuorikatu with 6 floors located in Helsinki) included necessary actions as follows

- refurbishment of facades and windows

Possible energy saving actions covered

- renewing of windows (U –value 1.8 → 1.0 W/m^2K))
- external insulation (by 100 mm mineral wool).

Table 42. Economical analysis of energy renovation of Vuorikatu 22.

Ilmarinen	Vuorikatu 22		
Total room-area	4 120 room-m^2	Necessary costs + costs of energy saving	Necessary costs
Change in heating energy consumption	MWh/a	-125	
1. ACQUISITION COST			
Refurbishment of facades 1623 m^2	€	155 000	114 000
Refurbishment of windows 189 m^2/541 m^2	€	20 000	60 000
Renewing of windows 352 m^2	€	176 000	
Indirect costs	€	35 000	17 000
TOTAL	€	386 000	191 000
TOTAL	€/room-m^2	94	47
2. LIFE CYCLE COST IN 20 YEARS			
Acquisition cost	€	195 000	
Resale value	€	-10 000	
Financial cost	€	49 000	
Heating cost (real rise of energy price + 4%/a)	€	-129 000	
TOTAL	€	105 000	
3. PAYBACK TIME	y	26	

The results show that economically justified improvement of energy economy is always connected to condition survey and user needs.

7.4.3 Conclusions

The possibilities to remarkably improve energy efficiency in economical ways are directly connected to needs for extensive renovation of an outdated building. However, also separately done changes of windows, refurbishment of facades etc. should lead to the reasonable improvement of energy performance.

Development and utilization of renovation concepts means progressive ways of management renovation. The economic impacts of concepts can be summarized as follows.

- significant reduction of energy consumptions and carbon foot print
- reasonable increase of investment cost
- reasonable savings in life cycle costs
- increase of resale value
- better motivation of workers through successful concepts.

The most remarkable risks concern

- management of changes in energy production
- adequacy and management of movements of labour connected to timing, quality and cost demands
- management of damage mechanisms of façade structures
- possible cost and health effects of individual unsuccessful refurbishments
- technical possibilities to improve U-value of historically valuable facades
- increase of unexpected connected works caused by extra insulation of facades.

Most remarkable possibilities concern

- renovation concept and product innovations
- adequate training programmes of companies and labour
- new kind of financing and supporting mechanisms
- creating concepts where extensive renovations are carried out in context to big local refurbishment projects.

The most durable increase of economic value (market value) by means of extensive renovation can be achieved when the building or the block of buildings is located in a relatively valuable neighbourhood and when the whole neighbourhood is renovated at the same time. In these cases the costs of renovation can be compensated with help of the increase of market value. This can also be realised by increasing the density of the area. The increased use of sustainable building classification methods may also increase the valuation of renovated areas. Effects on economic values of houses and buildings and departments may be significant because of improved performance and because of aesthetical improvement.

Replacing of ventilation system is usually based on

- needs to improve healthy indoor climate and comfort (adequate and clean ventilation)
- effective heat recovery which may cause remarkable savings I heating energy
- adjustable ventilation in departments.

Typical questions concerning cost optimization of renovation projects

- Does the investor have relevant information about potential financing sources?
- Which sources of information or guidance are most useful in this regard?
- How can the net present value of energy saving be calculated, taking into account the uncertainty regarding future energy prices?
- How can value for money best be assessed in the context of energy performance contracts?

What type of contractual penalties or incentives might be used to secure compliance with specific environmental or social obligations?

7.4.4 Special issues of renovation of office buildings

This Section presents recommendations for sustainable renovation of office buildings. The recommendations concern typical office buildings and their energy saving objectives especially in Senate Properties [Senate Properties]. The technical possibilities to improve energy efficiency are divided in structural technologies and HVAC systems.

Renovation of an office building is always a result of extensive planning process based on condition survey, user needs, financial framework and technological possibilities to improve energy efficiency. The results presented in Table 1 are based on collected and combined information in Senate Properties. Those show possibilities to improve energy efficiency as a guide of low energy construction of office buildings [RIL 259-2012 2012].

A review concerning typical office buildings energy efficiency objectives is presented in the following Table 43.

Table 43. Needs for renovation of typical office buildings.

Typical office building	Typical performance and conditioning basis	Energy saving objectives
Old protected buildings -1940 Connected to district heat: 70…80% Class of energy efficiency: B…D Class of inner climate: S3	Central location, valuable facade and detail Gravitational removal ventilation Structural damages Low modification rate Inefficient and non-working workplace	Refurbishment of damages Replacing of roof Replacing of windows Improvement of tightness Improvement of workplace Optimal improvement of HVAC technology Optimal improvement of electrical systems Improvement of information systems Optimization of lightning and natural light
Traditional office buildings 1941–1960 Connected to district heat: 60…70% Class of energy efficiency: F…G Class of inner climate: S3/S2	Plastered or wooden surface Gravitational removal ventilation Low energy efficiency	Refurbishment of damages Replacing of roof Replacing of facades Replacing of windows Improvement of tightness Improvement of workplace Optimal improvement of HVAC technology Optimal improvement of electrical systems Improvement of information systems Optimization of lightning and natural light
Prefabricated office buildings 1961–1977 Connected to district heat: 85…90% Class of energy efficiency: E…F Class of inner climate: S3/S2	Poor tightness Poor insulation level Low modification rate Structural damages Low space-efficiency and quality	Refurbishment of damages Replacing of roof Replacing of facades Replacing of windows Improvement of tightness Improvement of workplace Optimal improvement of HVAC technology Optimal improvement of electrical systems Improvement of information systems Optimization of lightning and natural light

Typical office building	Typical performance and conditioning basis	Energy saving objectives
Prefabricated office buildings 1978–1994 Connected to district heat: 93…96% Class of energy efficiency: C…D Class of inner climate: S1/S2	Uncontrolled ventilation. Low modification rate Low space-efficiency and quality	Refurbishment of damages Increasing insulation of facade with new surface. Replacing automation and adjustment technology of HVAC systems Optimal improvement of electrical systems Improvement of information systems Optimization of lightning and natural light
Modern office buildings 1995- Connected to district heat: 97…99% Class of energy efficiency: B…C Class of inner climate: S1/S2	Change need to work place. Good inner circumstances High quality level Relatively low energy efficiency	Refurbishment of damages Improvement of workplace Improvement of information systems Replacing adjustment technology of HVAC systems

Structural technology

The importance of structural solutions to energy efficiency is remarkably lower in the case of office buildings than in residential buildings. However, it is both building physically and economically reasonable to increase insulation of those structures that need refurbishment or replacing. Guidelines are presented in the following:

Ground floors

The change of insulation with more energy efficient material is recommended if the floor surface has to be replaced in all cases. However, the importance of insulation level of ground floor is relatively low.

Facades

Outer extra insulation to facades usually increases the thickness meaning need for changing of windows and outer doors. The choice of insulation material and type of window is important also from architectural and spatial points of view. Replacing damaged facades with remarkable more energy efficient structures means usually also change of windows.

Roofs

It is easy to increase insulation to roof with attic or airing. It may be set both as blow wool and mineral wool. The demand for open ventilation holes and height of attic set boundaries to insulation increase. In case of flat roofs, the increase of insulation is possible only in the cases of replacing roof covering. The recommended solution is to use polyurethane.

Windows

The area of windows may be 10…50% of total room-area of office houses. Thus the importance of replacing old windows with 2 glasses to energy-efficient windows is relatively high. The acquisition cost of very energy-efficient window is 20…30% higher than an ordinary window with 3 glasses. However it is not economic justified to change windows having satisfactory condition to new ones only because of willingness to improve energy saving.

HVAC technology

Restrictions in usable space set demands of extra works for HVAC systems. Remaining existing parts of systems do also influence on planning possibilities.

When the architecture enables, cooling may be carried out either by cooling beams or blower convectors. However tight spaces on floors may lead to relatively low air flows.

The service division cannot usually be carried out in optimal way because of tight ventilation machine spaces. For the same reason a water-glycol system with lower coefficient of efficiency must be chosen.

Restrictions of usable spaces mean also less space for machines and channels of ventilation. Then the energy consumption of blasting remains higher than in the case of new buildings.

8. Finnish residential building stock and its modelling

8.1 Introduction

MECOREN project studied the potential of different renovation methods from the view point of energy savings and reduction in GHGs. In order to model the Finnish residential building stock, statistical information was collected and summarized. This Chapter presents the basic composition of the Finnish residential building stock and describes the MECOREN tool developed in the project.

The Finnish residential building was divided into three different building types with help of statistical data. These building types are detached houses, attached houses and residential blocks of flats. Detached houses are residential buildings with 1–2 dwellings, attached houses have three or more dwellings attached together, and residential blocks of flats have three or more attached dwellings, placed on top of each other in two or more levels.

The properties of different building types change over time. Development of new construction methods and materials and changing building regulations are sources for the change. Detached houses from the 1970’s, for example, have quite different construction materials, structures and surface areas than those built today. Due to this, the building stock cannot be reliably described in terms of only one or two “typical buildings”.

This study divides the three building types into nine different age-groups the performance of which is defined based on previous research and statistical information. The typical performance for each of the age-type-groups (such as detached house, built between 1980 and 1979) are then defined in terms of building area, building volume, floor height, number of dwellings and number of inhabitants. Also typical structures, their U-values and surface areas, are defined for each of the age-type groups.

In addition to building structures and surface area, also the building systems play a big role in energy consumption of buildings. It is easy to understand that, for example, detached houses from the 1970’s with electrical heating consume more electricity than wood-heated houses of the same era. For this reason, each of the building types are further divided into subtypes, based on their heating method.

The following subchapters discuss the data used and present the composition of the Finnish residential housing stock.

8.2 Composition of the residential building stock

This study divides the Finnish residential housing stock into three different building types: detached houses, attached houses and residential blocks of flats.

The building type is determined according to the purpose for which the largest part of the gross floor area of the building is used. The year of construction refers to the year in which the building was completed and was ready for use.

The gross floor area of a building comprises the floor area of the different storeys and the area of attic or basement storeys in which there are dwelling or working rooms or other spaces confirming to the intended use of the building. The gross floor area is the horizontal area enclosed by the outer surfaces of the wall of the storeys.

The first table presents the gross floor area of residential buildings, based on their construction year and building type.

The detached houses have typically only single dwelling, whereas attached houses and residential blocks of flats have a number of them. The second table presents number of buildings in the Finnish housing stock, and the third table the corresponding number of dwellings.

Table 44. Floor area of residential buildings by construction year and building type. [Statistics Finland 2011].

Construction year	Detached houses (floor area, m^2)	Attached houses (floor area, m^2)	Residential blocks of flats (floor area, m^2)	Sum (floor area, m^2)
->1920	7 861 093	298 131	2 419 008	10 578 232
1921–1939	7 311 690	172 284	4 874 608	12 358 582
1940–1959	25 707 065	494 981	9 016 469	35 218 515
1960–1969	14 081 347	1 913 140	15 864 934	31 859 421
1970–1979	22 011 443	7 647 045	23 541 282	53 199 770
1980 –1989	29 158 961	11 484 936	12 043 634	52 687 531
1990–1999	18 973 584	5 734 341	10 832 394	35 540 319
2000–2008	20 077 600	4 078 161	9 308 603	33 464 364
Unknown year	2 965 023	309 566	691 041	3 965 630
Sum	148 147 806	32 132 585	88 591 973	268 872 364

Table 45. Number of buildings, divided by construction year and building type. [Statistics Finland 2011].

Construction year	Detached houses	Attached houses	Residential blocks of flats
–1920	63 792	757	1 826
1921–1939	66 909	496	3 048
1940–1959	241 131	1 084	6 898
1960–1969	116 598	3 243	8 684
1970–1979	157 396	14 411	12 673
1980–1989	197 510	28 811	9 061
1990–1999	124 321	15 751	8 114
2000–2008	122 628	9 581	5 136
Unknown year*	22 267	721	436
Sum	**1 112 552**	**74 855**	**55 876**

Table 46. Number of dwellings, divided by construction year and building type. [Statistics Finland 2011].

Construction year	Detached houses	Attached house	Residential blocks of flats
–1920	63 792	3 806	23 480
1921–1939	66 909	2 506	62 365
1940–1959	241 131	5 401	126 262
1960–1969	116 598	19 127	228 381
1970– 1979	157 396	90 265	334 630
1980–1989	197 510	140 313	164 868
1990–1999	124 321	72 334	149 147
2000– 2008	122 628	44 788	121 901
Unknown year*	22 267	3 682	9 521
Sum	**1 112 552**	**382 222**	**1 220 555**

Table 47. Number of inhabitants in different building types. [Statistics Finland 2011].

Construction year	Detached houses	Attached houses	Residential blocks of flats
-1920–2008	2 661 217	696 304	1 757 013

8.3 Mecoren-tool

MECOREN project developed an Excel-based MECORE TOOL. The tool enables analyses of the impacts of different refurbishment actions on Finnish building stock, in terms of energy use and carbon footprint of residential buildings. The following subchapters give a brief description explanation of the calculation method.

8.3.1 Modelling of the Finnish residential housing stock and calculation method

The composition of the Finnish residential building stock is used as an input for the tool. The Finnish residential housing stock is divided into three different groups by the main type of the building. The three main groups of the buildings in the residential buildings stock are: detached houses, attached houses, and residential blocks of flats.

The following figure illustrates how the building stock is divided into these three groups.

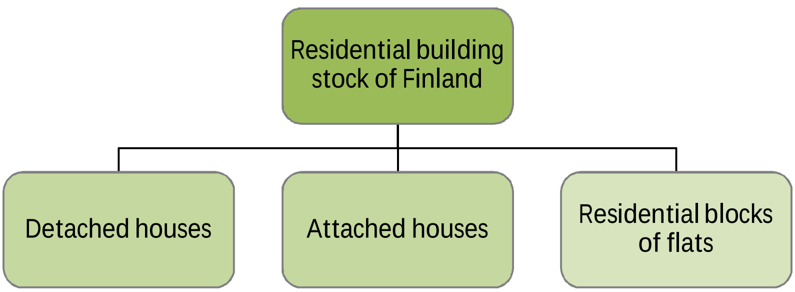


Figure 65. Residential buildings, main building types.

These main groups were further divided into eight different groups by their building year. The following figures uses detached houses as an example to show this division, which applies to all three main building types.

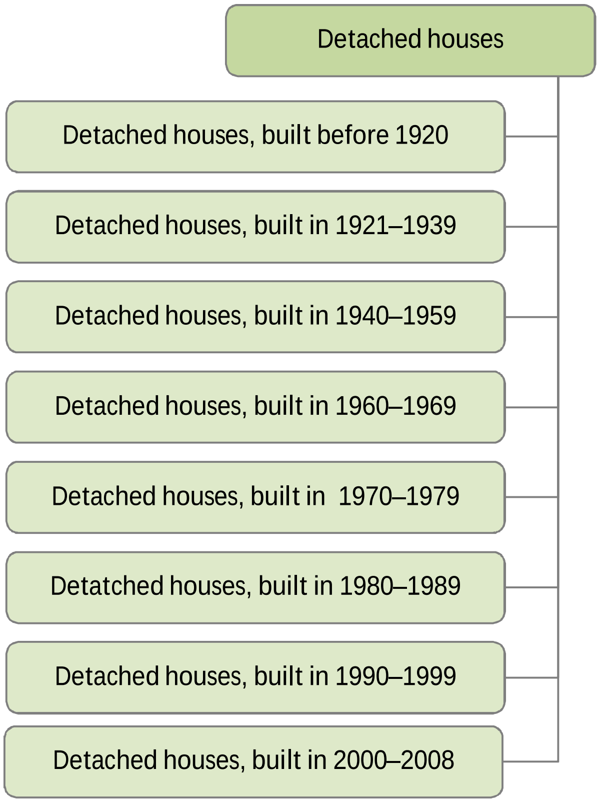


Figure 66. Different age-groups for buildings, detached houses as an example.

Finally, each of the age-groups were divided into groups, based on their heating method. The detached houses were categorised into buildings with oil, wood, district, electric and geothermal heating systems. Attached houses were divided into buildings with oil, district and electric heating. The residential blocks of flats were divided into buildings with oil heating and district heating. The following figures uses detached houses, built in 1940–1959, as an example to illustrate this division.

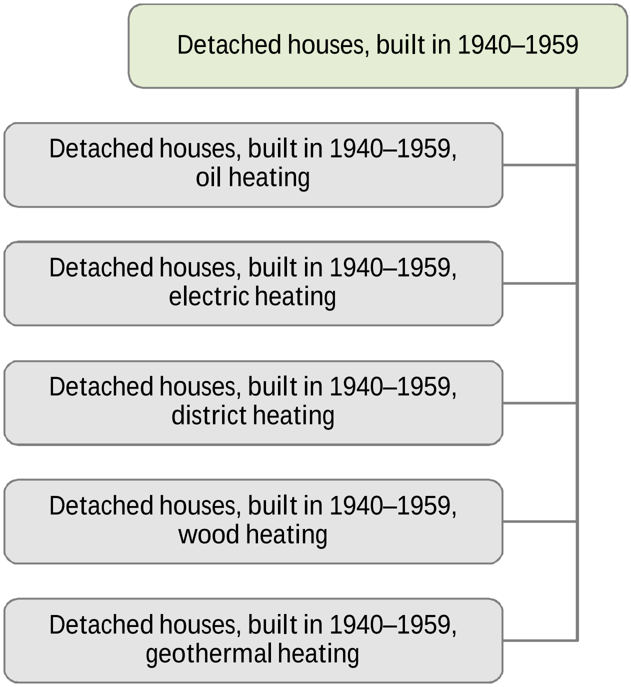


Figure 67. Different heating methods of detached houses, detached houses built in 1940–1959 as an example

A model building for each of these building types was then created with energy calculation tool WinEtana, so that the energy consumption of each of these could be calculated. The inputs for each of the building types were based on statistical information and expert analyses on properties of different building types. These general properties are presented in more detail in the following chapters.

After all the model buildings were created, the energy consumption of the whole stock was calculated. The result was compared to statistical data on energy consumption of buildings, and the properties of model buildings were altered in steps to match the real energy consumption of buildings. As a result, the energy consumption of the model buildings of this research matches with the real energy consumption of the Finnish residential housing stock at a reasonable accuracy. The energy consumption of each of the model buildings is presented in Appendix B.

Greenhouse gas emission calculations are made by multiplying the energy use of the residential housing stock with respective GHG emission-profiles. Different profiles are used for oil-heating, electric heating, district heating and wood heating.

8.3.2 Modelling the size of the Finnish housing stock in 2020 and 2030

The size of the existing building stock will develop over time, as buildings exit the stock due to various reasons. The Mecoren-tool takes this into account by using specific "exit rates" for each of the age-type groups of the buildings. These are presented in more detail in the latter chapters.

Figure 68 taken from the Mecoren-tool, shows how the amount of detached houses will develop over time, from 2010, until 2020 and 2030.

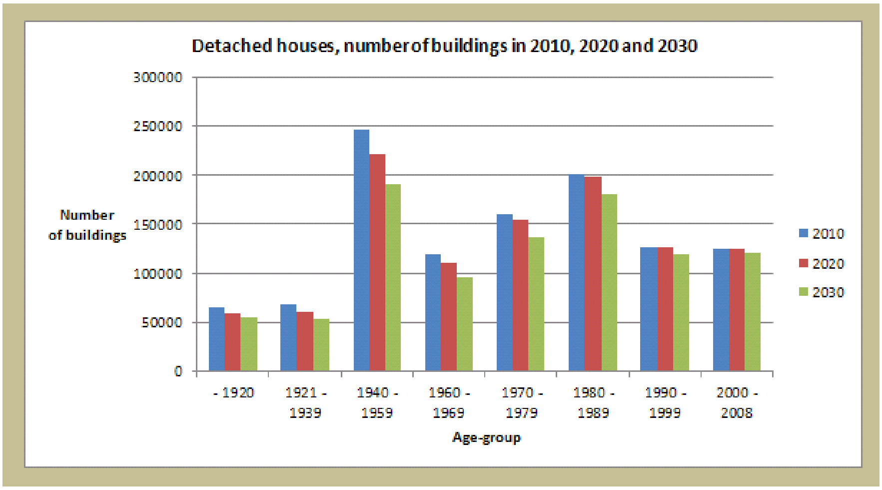


Figure 68. Number of detached houses in 2010, 2020 and 2030. Figure taken from Mecoren-tool.

8.3.3 Modelling the renovation need of the building stock in 2020 and 2030

The natural renovation cycles of buildings have an important role in calculations, since many of the energy renovations are feasible (profitable) only when other renovations also take place. Mecoren-tool assumes that energy renovations can only be done on buildings, in accordance to their natural renovation cycles. This is taken into account by using specific estimates for renovation needs of each of the age-type groups of buildings. These are presented in more detail in the latter chapters. Figure 69 taken from the Mecoren-tool, shows the renovation need of detached houses, in 2010–2020, and in 2020–2030.

Thorough renovations		
Building Year	Predicted refurbishment need, no. of buildings	
	2010-2020	2020-2030
- 1920	15038	12965
1921 - 1939	17274	13674
1940 - 1959	74435	53400
1960 - 1969	37750	31711
1970 - 1979	47449	45973
1980 - 1989	45351	69656
1990 - 1999	25372	30285
2000 - 2008	0	25026

Figure 69. Detached houses in need of renovations in 2010–2020 and in 2020–2030. Figure taken from Mecoren tool.

8.3.4 Modelling the energy use of buildings after renovations

The energy consumption of buildings after renovations was calculated with the model buildings. Five different renovation methods were applied on each of them.

For example, the model building for detached houses built between 1940–1959 with oil-heating was used as the base-case for buildings with no renovations. The different renovation alternatives were calculated with new model buildings. One of the model buildings modelled an oil-heated building of 1940–1959 with passive level window renovation, one with passive level roof and walls, one with ventilation renovation, one with solar-heat installation, and one with a combination of the other four, was created.

The following figure illustrates the different renovation cases, using detached houses built in 1940–1959 with oil heating, as an example.

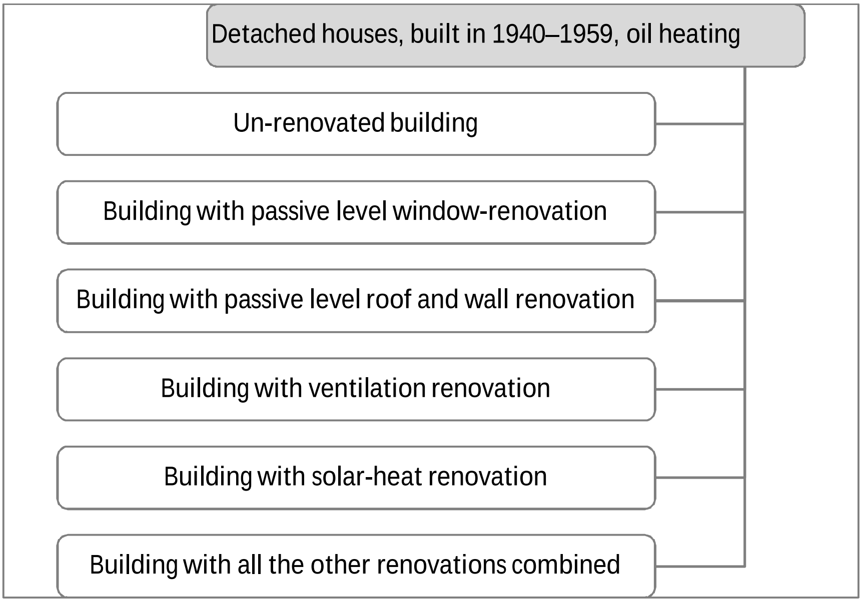


Figure 70. Different renovation alternatives, oil-heated detached houses built in 1940–1959 as an example.

The calculation results from all the base-case and all the renovation cases were then used as an input for the Mecoren-tool. In other words, the tool has detailed information about the energy consumption of each of the building types, divided by their age and heating method, and for five different renovation cases for each of them. All of these results are shown in the appendices.

9. Properties of typical residential buildings and their use in energy calculations of the Finnish housing stock

9.1 Introduction

In order to calculate energy consumption of a building stock, both the size of the stock, and the typical performance of buildings needs to be known. With this information, it is possible to calculate the energy consumption of building types on a building stock level. This is done by multiplying the energy consumption of a building type with the number of buildings in the stock.

Eventually, the total energy consumption of the housing stock can be calculated by adding the results of single building types.

This Chapter and its subchapters describe the properties of typical buildings of the Finnish housing stock, based on statistical data and previous research.

The first subchapter defines the general dimensions of the buildings, in terms of building area, volume, floor height and number of dwellings and number of inhabitants for each of the age-type groups of buildings.

The second subchapter describes the structures and properties of building envelopes, by defining typical construction materials for building frame, and U-values and surface areas of building envelope components.

Subchapter three discusses the ventilation systems, ventilation rates and air leakage rates of buildings.

Subchapter four analyses the electricity consumption of buildings, in terms of electricity consumption of household devices, lighting, oil burners and service and heating water networks.

Subchapter five discusses heating systems and fuels and points out the most common heating methods for each of the building types.

Finally, subchapter six gives an understanding of how the data presented in this chapter is used in energy consumption calculations.

9.2 Building area, volume, floor height, number of dwellings and number of inhabitants

This chapter defines the general dimensions of the buildings, in terms of building area, volume, floor height and number of dwellings and number of inhabitants for each of the age-type groups of buildings.

The average floor area for each building type and age-group is calculated by using the information presented in Tables. When total floor area of as single building type is divided by the corresponding total number of buildings, an average floor are for a building can be calculated.

The average floor areas can then be used for calculating the average building volumes, when they are multiplied with the average floor heights. The values for average floor heights are based on EkoREM K-1998 calculations. [Heljo et al. 2005].

The number of inhabitants is calculated based on the following: An average floor area per inhabitant is first calculated for all three building types. The number of inhabitants per building can then be calculated by dividing average building areas by the floor areas per inhabitant. The following tables present the floor areas, volumes, floor heights and inhabitant numbers for the three building types.

Table 48. Floor areas, volumes, floor heights and inhabitant numbers for detached houses of different age-groups.

Building Age-group	Building area, m^2	Building volume, m^3	Floor height, m	Number of inhabitants
–1920	123	383	3.11	2.3
1921–1939	109	340	3.11	2.0
1940–1959	107	333	3.12	2.0
1960–1969	121	374	3.10	2.2
1970–1979	140	443	3.17	2.6
1980–1989	148	475	3.22	2.7
1990–1999	153	499	3.27	2.8
2000–2008	164	535	3.27	3.0

Table 49. Floor areas, volumes, floor heights and inhabitant numbers for attached houses of different age-groups.

Building Age-group	Building area, m^2	Building volume, m^3	Floor height, m	Number of dwellings	Number of inhabitants (whole building)
–1920	394	1 205	2.45	5.0	9
1921–1939	347	1 070	2.69	5.1	8
1940–1959	457	1 402	2.85	5.0	10
1960–1969	590	1 793	3.09	5.9	13
1970–1979	531	1 629	3.11	6.3	12
1980–1989	399	1 220	3.06	4.9	9
1990–1999	364	1 161	3.12	4.6	8
2000–2008	426	1 349	3.28	4.7	9

Table 50. Floor areas, volumes, floor heights and inhabitant numbers for residential blocks of flats of different age-groups.

	Building area, m^2	Building volume, m^3	Floor height, m	Number of dwellings	Number of inhabitants (whole building)
–1920	1 325	5 299	3.60	13	26
1921–1939	1 599	5 709	3.57	20	32
1940–1959	1 307	4 601	3.55	18	26
1960–1969	1 827	5 992	3.43	26	37
1970–1979	1 858	6 372	3.42	26	37
1980–1989	1 329	4 532	3.42	18	27
1990–1999	1 335	4 566	3.49	18	27
2000–2008	1 812	6 108	3.69	24	36

9.3 Typical structures for buildings of different age

This Section describes the structures and properties of building envelopes, by defining typical construction materials for building frame, and U-values and surface areas of different parts of building envelope.

The first subsection gives general information of the load-bearing structures of the Finnish housing stock. The following subsections discuss U-values and surface areas of different components of building envelope.

9.3.1 Building materials

This section gives information of the load-bearing structures of the Finnish housing stock.

Building materials here mean the material of the load bearing vertical structures. The building materials are classified into five different groups: concrete and light weight concrete, bricks, steel, wood, and other or unknown materials.

The next Tables show the building materials of the load bearing structures of different building types.

Table 51. Vertical load bearing structure of detached houses. Source: VTT's and Statistics Finland's housing data. As in 2008.

Detached houses	Sum of floor area, 1000 m^2	Concrete Floor area, 1000 m^2	Brick, floor area, 1000 m^2	Steel, floor area, 1000 m^2	Wood, floor area, 1000 m^2	Unknown + other, floor area, 1000 m^2
–1920	7 861	37	107	5	7 480	233
1921–1939	7 312	74	253	2	6 801	181
1940–1959	25 707	533	719	9	24 035	412
1960–1969	14 081	636	1 913	7	11 304	223
1970–1979	22 011	724	2 564	29	18 344	351
1980–1989	29 15 9	1 585	1 325	43	25 945	261
1990–1999	18 974	1 137	602	36	16 983	216
2000–2008	20 078	2 031	430	62	17 121	434
Unknown	2 965	187	84	11	2 532	152
sum	148 148	6 944	7 996	204	130 543	1 636
	100%	**5%**	**5%**	**0.1%**	**88%**	**2%**

Table 52. Vertical load bearing structure of attached houses. Source: VTT's and Statistics Finland's housing data. As in 2008.

Attached houses	Sum of floor area, 1000 m^2	Concrete Floor area, 1000 m^2	Brick, floor area, 1000 m^2	Steel, floor area, 1000 m^2	Wood, floor area, 1000 m^2	Unknown + other, floor area, 1000 m^2
–1920	298	7	15	2	270	4
1921–1939	172	7	15	0,5	149	1
1940–1959	495	109	131	5	231	20
1960–1969	1 913	621	483	0,6	782	26
1970–1979	7 647	2 325	945	35	4 252	89
1980–1989	11 485	3 521	397	11	7 523	33
1990–1999	5 734	1 413	87	8	4 211	14
2000–2008	4 078	1 436	31	15	2 584	12
Unknown	310	60	17	0,3	215	17
sum	32 133	9 499	2 120	77	20 218	217
	100%	**30%**	**7%**	**0.2%**	**63%**	**0.7%**

Table 53. Vertical load bearing structure of residential blocks of flats. Source: VTT's and Statistics Finland's housing data. As in 2008.

Residential block of flats	Sum of floor area, 1000 m^2	Concrete Floor area, 1000 m^2	Brick, floor area, 1000 m^2	Steel, floor area, 1000 m^2	Wood, floor area, 1000 m^2	Unknown + other, floor area, 1000 m^2
–1920	2 419	186	1 706	12	422	93
1921–1939	4 8758	1 053	3 246	15	514	46
1940–1959	9 017	4 602	3 482	15	777	140
1960–1969	15 865	13 681	1 736	41	232	174
1970–1979	23 541	22 235	718	78	286	225
1980–1989	12 044	11 688	150	21	140	45
1990–1999	10 832	10 429	44	48	277	35
2000–2008	9 309	9 082	28	41	150	29
Unknown	691	533	88	-	41	2
Sum	88 592	73 489	11 197	271	2 840	795
	100%	**83%**	**13%**	**0.3%**	**3%**	**1%**

9.3.2 U-values of building components

This section lists the U-values for different components of the building envelope. U-values for exterior wall, base floor, roof and windows are given for each of the age-groups.

It is assumed that the U-values of a certain time period are based on the regulations then. Detached houses, attached houses and residential blocks of flats of a certain time period have the same U-values.

Table 54. U-values of the building structures based on building regulations.

	Energy regulations	Exterior wall (W/m^2K)	Base floor (W/m^2K)	Roof (W/m^2K)	Window (W/m^2K)
->1920		0.85	0.475	0.475	3.14
1921–1939		0.85	0.475	0.475	3.14
1940–1959		0.85	0.475	0.475	2.79
1960–1969		0.6	0.475	0.39	2.79
1970–1979	1969	0.475	0.48	0.335	2.44
1980–1989	1985	0.3	0.31	0.24	2.1
1990–1999		0.28	0.22	0.22	2.1
2000–2008	2003	0.26	0.18	0.18	1.4

9.3.3 Surface areas of building components

This section presents the estimated surface areas of different building envelope components for all building types. The estimates are based on expert estimations about average building shape, surface area, and calculated values. It is estimated that average detached and attached houses are 1-storey buildings, and residential blocks of flats are 5-storey buildings.

The next Table presents the surface areas of the exemplary buildings, including walls, roof, floor and windows. 50% of the total window area is assumed to be south-facing, 25% north-facing, 12.5% east-facing and 12.5% west-facing.

Table 55. Surface areas of detached houses, estimated.

Detached house	Wall area, m^2	Roof area, m^2	Floor area, m^2	Window area, m^2
–1920	128	150	150	17.5
1921– 1939	125	127	127	14.8
1940–1959	120	121	121	14.2
1960–1969	130	149	149	20.0
1970–1979	132	152	152	20.5
1980–1989	129	126	126	14.7
1990–1999	131	124	124	14.5
2000–2008	144	140	140	16.4

Table 56. Surface areas of attached houses, estimated.

Attached house	Wall area, m^2	Roof area, m^2	Floor area, m^2	Window area, m^2
–1920	189	418	418	49
1921–1939	200	361	361	42
1940–1959	271	663	589	78
1960–1969	304	689	603	81
1970–1979	275	518	504	61
1980–1989	241	391	391	46
1990–1999	232	337	337	39
2000–2008	259	379	379	44.

Table 57. Surface areas of residential blocks of flats, estimated.

Residential block of flats	Wall area, m^2	Roof area, m^2	Floor area, m^2	Window area, m^2
–1920	1 127	536	430	251
1921–1939	1 182	625	475	292
1940–1959	1 026	441	377	206
1960–1969	1 067	544	434	255
1970–1979	1 030	500	410	234
1980–1989	865	324	302	151
1990–1999	867	307	291	144
2000–2008	1 009	378	338	273

9.4 Ventilation systems

This section presents the ventilation systems for buildings of different age. It is assumed that ventilation systems of a certain period do not vary between the building types. In other words, detached houses, attached houses and residential blocks of flats of a certain time period all share same type of ventilation system.

The ventilation system of buildings built before 1980 is thought to be natural ventilation. For buildings built between 1980 and 1999, it is assumed that the ventilation system has natural supply air and mechanical exhaust air system. All the buildings built since 2000, are assumed to be equipped with mechanical supply and exhaust ventilation with heat recovery system.

The air-change rate of the building with a natural ventilation system was estimated to be only 0.3 1/h (including the air-leakage of the building envelope), because of the inefficiency of the system.

The air-tightness of existing buildings was estimated to be n50 = 4 for detached and attached houses and 2.5 for blocks of flats, which corresponds to hourly air leakage of 0.16 and 0.1 respectively. The next Table summarizes ventilation systems for different construction years (all building types).

Table 58. Type of ventilation system by construction year *=residential blocks of flats.

Construction year	Type of ventilation system (for all the building types)	Air-Change rate (excluding air-leakage), 1/h	Air-Change rate (including air-leakage), 1/h	Heat recovery efficiency
–1920	Natural	0.14	0.3	-
1921–1939	Natural	0.14	0.3	-
1940–1959	Natural	0.14	0.3	-
1960–1969	Natural/ Mechanical exhaust*	0.14/ 0.45*	0.3/ 0.55*	-
1970–1979	Natural/ Mechanical exhaust*	0.14/ 0.45*	0.3/ 0.55*	-
1980–1989	Mechanical exhaust	0.45	0.55	-
1990–1999	Mechanical exhaust	0.45	0.55	-
2000–2008	Mechanical supply and exhaust, with heat recovery	0.45	0.55	50%

9.5 Electricity use

This section presents the electricity consumption of buildings, in terms of electricity consumption of household devices, lighting, oil burners and service and heating water networks. The data presented in this section is mainly based on research by Adato [2006]. Number of dwellings, average electricity use per household and the total energy consumption are based on information from 2006.

Table 59. Household electricity use by building type in 2006. [Adato 2006].

	Dwellings	Average use, kWh/a	Total use, GWh/a
Detached houses	996 263	7 550	7 522
Attached houses	340 979	3 525	1 202
Residential block of flats	1 065 423	2 109	2 247

9.5.1 Electricity consumption by household devices

The following Table presents the average household electricity use for each of the building types, divided between different device groups.

Table 60. Average household electricity use per device group.[Adato 2006].

Device group	Detached house, kWh/a	Attached house, kWh/a	Residential blocks of flats, kWh/a
Fridge and freezer	768	522	460
Electrical sauna stove	600	416	85
Entertainment	424	329	266
Food preparation	302	275	230
Laundry	224	146	103
PC etc.	178	160	158
Dishing machine	167	101	51
Other devices	2 153	438	190
Car heating	187	67	-
Outdoor lighting	71	34	-

* in residential blocks of flats, the electricity use of the heating system belongs to the estate electricity use; this number represents the mechanical ventilation devices in apartments.

9.5.2 Lighting electricity consumption

Lighting electricity use calculations are based on the annual average electricity use of energy-efficient fluorescent lamps (4.3 kWh/m^2). The lighting energy consumption for .each of the building types is presented in Table.

Table 61. Average lighting electricity consumption.

	Detached house, kWh/a	Attached house, kWh/a	Residential block of flats, kWh/a
–1920	443	337	378
1921–1939	409	250	295
1940–1959	430	377	299
1960–1969	525	415	296
1970–1979	636	356	295
1980–1989	542	345	306
1990–1999	533	316	288
2000–2008	602	349	274

9.5.3 Oil burner electricity use

The oil burners of oil-heated buildings contribute to the total electricity consumption in these types of buildings. The annual total electricity use of the oil burners of oil-heated detached houses was 52 GWh in year 2000 [Korhonen et al. 2002]. The amount of oil-heated detached houses was 260 000. If the average volume of a detached house is 467 m^3, the total volume of oil-heated detached houses is

121 329 700 m^3. Dividing the total electricity use 52 GWh with the total volume, we get the specific electricity use of the oil burner 0.43 kWh/m^3.

For example a detached house with the average volume of 467 m^3 the annual electricity use of the oil burner is 200 kWh/a. The calculated specific electricity use of the oil burner is also used in estimating the oil burner electricity use of attached houses and block flat houses. The average oil burner electricity use for each of the building types is presented in Table.

Table 62. Average oil burner electricity use per building considering only oil-heated building.

Equipment	Detached house	Attached house	Residential block of flats kWh/a
1920	184	438	3309
1921–1939	163	416	3822
1940–1959	156	809	2683
1960–1969	193	912	3199
1970–1979	199	690	2933
1980–1989	170	513	1897
1990–1999	171	450	1839
2000–2008	200	532	2392

9.5.4 Electricity use of service water and heating water networks

This chapter presents the electricity use of service water and heating water networks.

The pumps of service and heating water networks require electricity to operate. The following Table presents the annual pump electricity use for each of the building types. The results are presented for both service water and heating networks.

Table 63. Average annual pump electricity use per building.

	Detached house, kWh/a		Attached house, kWh/a		Residential block of flats, kWh/a	
	service water	heating network	service water	heating network	service water	heating network
–1920	12	41	28	85	215	345
1921–1939	11	37	27	78	248	373
1940–1959	10	28	53	108	174	233
1960–1969	13	27	59	96	208	219
1970–1979	13	22	45	60	191	165
1980–1989	11	23	33	60	123	158
1990–1999	11	23	29	52	120	155
2000–2008	13	19	35	39	155	113

9.6 Heating systems and fuels

This Section discusses the different heating systems and heating fuels which are used in heating the buildings of Finnish housing stock.

The first subsection presents statistical data on heating systems of Finnish residential stock, and the second subchapter discusses the heating fuels.

The information on heating systems and fuels is compiled from statistics. The heating system means here the method used to heat the building, and the heating fuel refers to the main fuel or energy source.

Data on the heating fuel have been obtained from the Population Information System, which receives them from municipal building supervision authorities in the context of building project notices. Information about the change in the heating system is only transmitted to the Population Information System if such alterations have been done to a building which requires a building permit.

The heating systems are classified in the statistics with six different categories, which are:

- central heating, water
- central heating, air
- direct electric heating
- stove heating
- no fixed heating installation
- unknown heating method.

Each of these systems is further divided based on the heating fuel. The subcategories for the heating systems are as follows:

- oil
- heavy fuel oil

- electricity
- gas
- coal
- wood
- peat
- geothermal
- other, unknown.

9.6.1 Heating systems

In a water central heating system, the building is heated with circulating water, and in an air central heating system with circulating air. In direct electric heating the building is heated with the aid of a fixed radiator, etc. connected directly to the electricity network.

In stove heating, heating takes place by burning wood or other fuels in a fireplace (stove) that stores heat. Stove heating also includes electric heating reservoirs, separate fixed oil heaters and heat preserving fireplaces. Stoves used for heating saunas are not regarded as heating equipment.

The following tables present the relative share of heating source by construction year. The information is based on Nippala et al. [2005]. The first table presents the values for detached houses, second one for attached houses and the third one for residential blocks of flats. The relative shares of heating sources have been added to the original data tables

The calculations done in this research combine the relatively small shares of heavy oil, gas, coal, coke, and peat under light heating oil.

Table 64. Heated cubic meters and share of heating source and construction year for detached.

	Building stock, 2010	Wood, pellet	Light heating oil, POK	Heavy oil, POR	Gas	Coal, coke, peat	Electricity	Central heating	Geo-thermal
	1000-m^3	%	%		%	%	%	%	%
–1920	27 629	40%	19%	0.2%	0.1%	1%	36%	2%	1.2%
1921–1925	3 786	43%	21%	0.1%		1%	33%	2%	0.2%
1926–930	6 206	43%	21%	0.1%		1%	33%	2%	0.2%
1931–1935	4 368	43%	21%	0.1%		1%	33%	2%	0.2%
1936–1940	7 685	43%	21%	0.1%		1%	33%	2%	0.2%
1941–1945	5 190	35%	25%	0.2%		1%	37%	3%	0.1%
1946–1950	23 442	39%	23%	0.1%		1%	35%	2%	0.2%
1951–1955	25 346	35%	31%	0.2%		2%	30%	2%	0.2%
1956–1960	21 259	30%	40%	0.3%		3%	24%	2%	0.2%
1961–1965	19 284	25%	51%	0.2%	0.1%	2%	19%	3%	0.2%
1966–1970	22 459	16%	62%	0.3%	0.1%	1%	17%	3%	0.3%
1971–1975	29 925	10%	54%	0.2%	0.1%	0%	32%	3%	0.2%
1976–1980	42 085	16%	50%	0.2%		1%	23%	10%	0.3%
1981–1985	43 270	22%	7%	0.1%		0%	58%	11%	1.1%
1986–1990	43 705	11%	8%	0.1%	0.4%	0%	73%	7%	0.3%
1991–1995	29 845	8%	13%	0.1%	0.7%	0%	70%	7%	0.2%
1996–2000	24 379	7%	16%	0.2%	0.5%	0%	64%	10%	2.1%
2001–2005	28 485	6%	11%	0.1%	0.5%	0%	66%	10%	6.1%
2006–2010	28 485	6%	8%	0.1%	0.9%	0%	56%	15%	13.7%

Table 65. Heated cubic meters and share of heating source and construction year for attached houses.

	Building stock, 2010	Wood, pellet	Light heating oil, POK	Heavy oil, POR	Gas	Coal, coke, peat	Electricity	Central heating	Geo-thermal
	1000-m^3	%	%		%	%	%	%	%
–1920	1 319	10%	15%	0.7%	0.1%	0.4%	47%	26%	0%
1921–1925	123	17%	24%	0.6%		1.8%	39%	17%	0%
1926–1930	108	17%	24%	0.6%		1.8%	39%	17%	0%
1931–1935	53	17%	24%	0.6%		1.8%	39%	17%	0%
1936–1940	96	17%	24%	0.6%		1.8%	39%	17%	0%
1941–1945	91	13%	26%			0.7%	28%	33%	
1946–1950	171	18%	34%			0.8%	20%	27%	
1951–1955	345	3%	24%	3.6%	0.2%	0.2%	7%	63%	
1956–1960	805	2%	32%	2.0%		0.5%	3%	60%	
1961–1965	2 048	1%	36%	3.7%		0.1%	3%	57%	0%
1966–1970	4 185	1%	43%	0.7%	0.3%	0.1%	5%	50%	0%
1971–1975	10 459	0%	45%	0.6%	0.2%	0.0%	21%	32%	
1976–1980	13 934	0%	44%	0.3%	0.3%	0.1%	8%	47%	0%
1981–1985	17 510	1%	15%	0.7%	0.1%	0.1%	33%	50%	0%
1986–1990	18 583	0%	9%	0.5%	0.5%	0.0%	49%	41%	0%
1991–1995	8 310	0%	21%	0.5%	1.4%		28%	49%	0%
1996–2000	6 416	0%	13%	0.2%	2.2%		27%	57%	0%
2001–2005	6 791	0%	9%		0.7%		34%	57%	
2006–2010	6 791	0%	7%	0.3%	1.2%		30%	60%	1%

Table 66. Heated cubic meters and share of heating source and construction year for residential block of flats.

	Building stock, 2010	Wood, pellet	Light heating oil, POK	Heavy oil, POR	Gas	Coal, coke, peat	Electricity	Central heating	Geothermal
	1000-m^3	%	%		%	%	%	%	%
–1920	10068	4%	7%	1%	0%	0%	6%	82%	
1921–1925	2303	2%	8%	0%	0%	0%	3%	86%	
1926–1930	6110	2%	8%	0%	0%	0%	3%	86%	
1931–1935	1859	2%	8%	0%	0%	0%	3%	86%	
1936–1940	6387	2%	8%	0%	0%	0%	3%	86%	
1941–1945	1815	5%	23%	1%		1%	5%	66%	
1946–1950	3505	4%	22%	1%	1%	0%	4%	68%	
1951–1955	10975	1%	15%	1%	0%	0%	1%	83%	0%
1956–1960	16956	0%	12%	2%	0%	0%	0%	85%	
1961–1965	27220	0%	15%	2%	0%	0%	0%	82%	0%
1966–1970	29996	0%	16%	3%	0%	0%	0%	81%	0%
1971–1975	47523	0%	16%	1%	0%	0%	1%	82%	
1976–1980	28569	0%	12%	0%	0%	0%	1%	87%	
1981–1985	21607	0%	5%	1%	0%	0%	3%	91%	
1986–1990	20087	0%	3%	0%	0%	0%	4%	92%	
1991–1995	19376		3%	0%	0%		1%	95%	0%
1996–2000	17137		2%	0%	0%		1%	97%	
2001–2005	19142		1%		0%		1%	98%	
2006–2010	19142		2%	0%	1%		0%	97%	

10. Energy consumption, CO_2-emissions and theoretical savings potential of Finnish residential housing stock

10.1 Introduction

According to 2010 statistics of energy use in Finland, the total end use of energy was 279 TWh (Chapter 3). The calculations of this research show (see the following sections) that the amount of annual heating energy use of residential buildings is 51 TWh, and the amount of household electricity use is 10 TWh (totalling 61 TWh). This means that total energy use of residential housing stock equals to about 22% of the total end-use of energy in Finland.

The OECD data on Finnish GHG emissions show that the annual emissions in Finland in 2009 were 66 million tonnes (Mt) (Chapter 3). The results of this research show that the GHGs resulting from heating energy use of residential buildings are roughly 13 Mt and the GHGs resulting from household electricity use are roughly 2.3 Mt. Together this equals to about 23% of the GHG emissions of Finland[3].

The absolute maximum savings potential of the Finnish residential housing stock can be assessed to equal to the current energy use and emissions of the housing stock. If the country-level energy use is to be reduced significantly, for example, by 5%...10%, by reducing heating energy need of residential buildings only, the heating energy use would need to be reduced greatly. If the heating energy demand of residential buildings could be cut by 30%, this would result in (15 TWh) 5% savings in country-level energy use, and if it could be cut by 60%, the savings would equal to (31 TWh) 10%.

The following sections present more detailed information on energy consumption and GHG-emissions of the current housing stock.

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[3] This result may overestimate the share of heating of building because the GHGs from heating are calculated on the bases of LCI but total GHGs are probably calculated in such a way that the extraction of fuels is not considered.

10.2 Energy consumption of the current housing stock

The heating energy use and electricity use were calculated for all residential buildings by using model buildings. The model buildings were created based on statistical information of Finnish residential housing stock, and expert analysis. An exemplary building was created to present each of the different age-type groups in the building stock, and these model buildings were then used for calculating the energy consumption of the housing stock.

The calculated total annual heating energy use is 50.6 TWh of which

- detached houses use 31 TWh (61%),
- attached houses use 5.5 TWh (11%) and
- blocks of flats 14.5 TWh (28%).

This means that the heating of residential buildings accounts for about 18% of the annual end-use of energy in Finland (total 279 TWh in 2010).

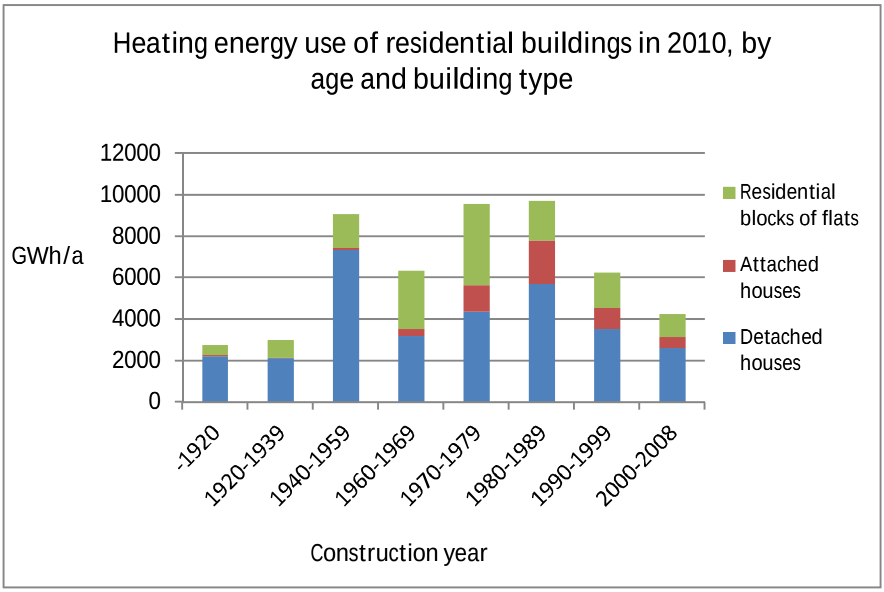


Figure 71. Annual heating energy use of residential buildings in 2010, divided by age and building type.

If the country-level energy use is to be reduced significantly, for example, by 5%...10%, by reducing heating energy need of residential buildings only, the heating energy use would need to be reduced greatly. If the heating energy demand of residential buildings could be cut by 30%, this would result in (15 TWh) 5% savings in country-level energy use, and if they could be cut by 60%, the savings would equal to (31 TWh) roughly 10%.

The eight most consuming building groups are listed in the following table. These eight building groups are responsible for a total of 33.5 TWh of heating energy consumption, which equals to about 66% of the heating energy consumption of the whole residential housing stock. The table shows that the three biggest consumers of heating energy are all detached houses. The biggest heating energy consumers are detached houses built between 1940 and 1950, detached houses built between 1980 and 1989 and detached houses built between 1970 and 1979. Two types of residential blocks of flats are included in the list. Those built between 1970 and 1979 and 1960 and 1969 are the biggest heating energy consumers. The biggest heating energy consuming group of attached houses are the buildings built between 1980 and 1989 which accounts for 2.1 TWh annually.

Table 67. Biggest heating energy consuming groups of buildings, 2010.

	Building type		Heating energy use (TWh)
1	Detached houses	1940–1959	7.327
2	Detached houses	1980–1989	5.716
3	Detached houses	1970–1979	4.368
4	Blocks of flats	1970–1979	3.954
5	Detached houses	1990–1999	3.533
6	Detached houses	1960–1969	3.202
7	Blocks of flats	1960–1969	2.802
8	Detached houses	2000–2008	2.596

The calculated total annual electricity use is 10. 2 TWh, from which

- detached houses use 6.3 TWh
- attached houses use 1.2 TWh and
- blocks of flats use 2.7 TWh.

The share of buildings' electricity use (10.2 TWh) is about 3.7% of the total end-use of energy in Finland (279 in 2010).

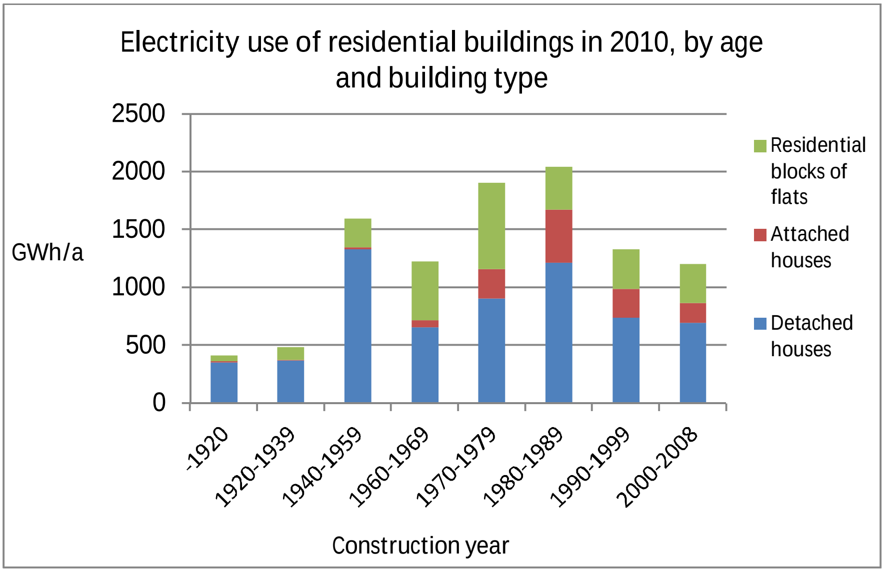


Figure 72. Annual electricity use of residential buildings in 2010, divided by age and building type.

10.3 GHG emissions of the current housing stock

The previous Section presented the calculation results of heating energy use and electricity use for the residential housing stock. This Section is based on those results, by attaching a specific environmental profile for each of the heating types. The results of this section are calculated by multiplying the amount of specific energy type used, for example district heating, by the emissions for producing that amount of energy. The environmental profiles for different energy types are based on research about Finnish energy production (see Chapter 3).

The calculated total annual CO_2-emissions from the heating energy use of the residential housing stock is 10.7 Mt. The share of detached houses is 6.05 Mt (57%), attached houses 1.35 Mt (12%), and residential blocks of flats 3.3 Mt (31%).

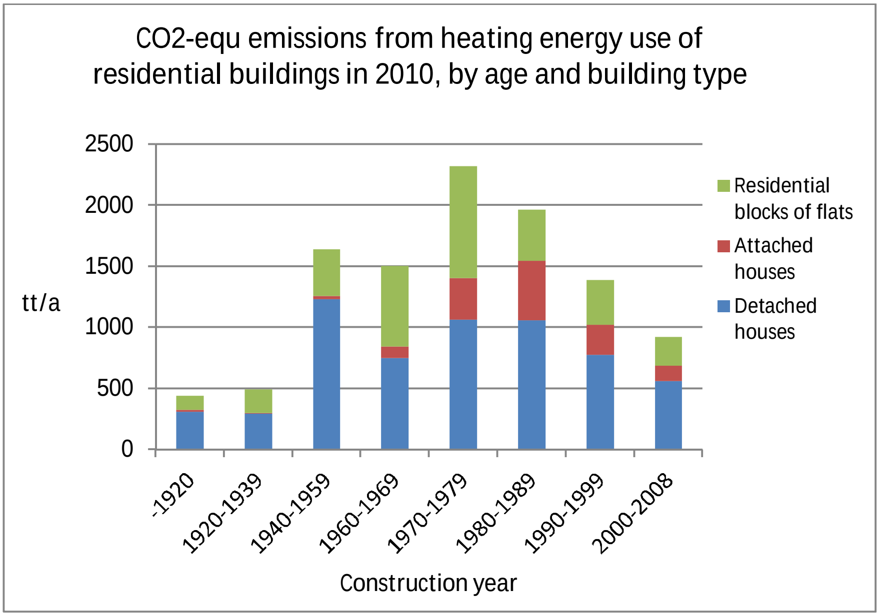


Figure 73. Annual CO_2-equ emissions of heating energy use of residential building stock, divided by heating method.

According to OECD statistics the total CO_2-equ emissions in Finland, in year 2010 were 66 million tonnes. The calculations of this research show that the amount of annual CO_2-equ emissions, resulting from heating energy use of residential buildings, is 10.7 Mt. The heating of residential buildings accounts for about 16% of the annual CO_2-equ emissions in Finland. This result may overestimate the share of heating of building because the GHGs from heating are calculated on the bases of LCI but total GHGs are probably calculated in such a way that the extraction of fuels is not considered.

If the country-level CO_2-equ emissions are to be reduced significantly, for example, by 5%...10%, by reducing emissions from heating of residential buildings only, the CO_2-equ emissions would need to be reduced greatly. If the CO_2-equ emissions from heating of residential buildings could be cut by 30%, this would result in (3.3 Mt) 5% savings in country-level CO_2-equ emissions, and if they could be cut by 60%, the savings would equal to (6.6 Mt) 10%.

The eight building types with the biggest CO_2-emissions are listed in the following table. These eight building types are responsible for a total of 7 million tonnes of CO_2-emissions annually, which equals to about 66% of the CO_2-emissions of the whole residential housing stock. The table shows that the three biggest CO_2 emitters of are all detached houses. The biggest share of CO_2-emissions result from the heating of detached houses built between 1940 and 1950, detached houses built between 1970 and 1979 and detached houses built between 1980 and 1989. Two types of residential blocks of flats are included in the list. Those built between 1970 and 1979 and 1960 and 1969 are responsible for the biggest share of CO_2 emissions of residential blocks of flats.

Table 68. The group of attached houses with biggest CO_2-emissions are the buildings built between 1980 and 1989, which account for 490 thousand tonnes of CO_2-emissions annually.

	Building type		CO_2-emissions (Mt)
1	Detached houses	1940–1959	1.233
2	Detached houses	1970–1979	1.064
3	Detached houses	1980–1989	1.057
4	Blocks of flats	1970–1979	0.917
5	Detached houses	1990–1999	0.776
6	Detached houses	1960–1969	0.753
7	Blocks of flats	1960–1969	0.660
8	Detached houses	2000–2008	0.563

The annual CO_2-equ emissions from residential buildings' electricity use are 2.3 Mt from which detached houses account for 1.4, attached houses for 0.3, and blocks of flats for 0.6 Mt. The share of CO_2-equ emissions from buildings' electricity use (2.3Mt) is about 3.5% of the total CO_2-equ emissions in Finland (66 Mt in 2010). Again this result may overestimate the share of heating of building because the GHGs from heating are calculated on the bases of LCI but total GHGs are probably calculated in such a way that the extraction of fuels is not considered.

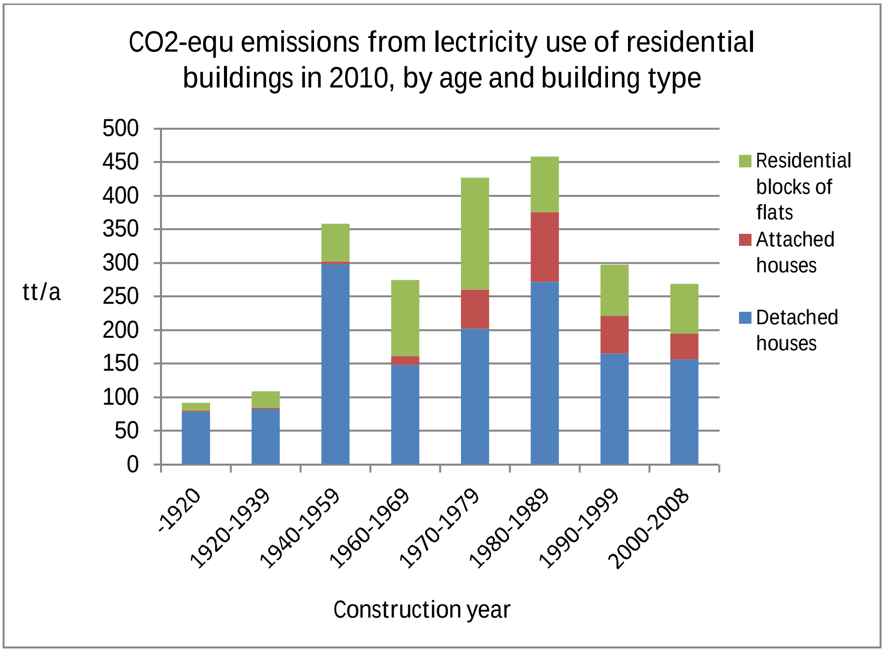


Figure 74. Annual CO_2-equ emissions from electricity use of residential building stock, divided by heating method.

10.4 Theoretical maximum energy- and CO2-savings potential of the Finnish residential housing stock

On the bases of the calculated results, the theoretical absolute maximum savings potential for heating energy use equals to 50.6 TWh, and for electricity, 10.2 TWh. In terms of CO_2-equ emissions, the savings potential for heating equals to 10.7 Mt and for electricity, 2.3 Mt. This section analyses the theoretical maximum energy saving potential of the building stock, when all the current buildings are thought to be renovated with a specific methods of renovation. This calculation does not give realistic savings potential for different renovations, but it gives a reasonable estimate about relative effectiveness of renovations.

10.4.1 Analysed renovation methods

Four different renovation methods were analysed in these calculations. Also, a combination of these renovations was analysed. The renovation methods under study were: passive level building envelope, ventilation renovation, solar heat installation and window renovation:

- passive level outer walls and roof
- passive- level windows (U = 0.7 W/m^2K) and improved air-tightness of the building envelope (4.0 -> 3.0 for detached and attached houses, 2.5 -> 2.0 for blocks of flats)
- renovation of ventilation system to mechanical supply and exhaust system with A-class fans and 75% yearly heat recovery efficiency
- utilization of solar heat for heating of service water (50% of the annual service water heating demand)
- a combination of the four renovations.

The passive level envelopes means a renovation where heating energy use was calculated for all building types with passive level insulation of outer walls and roof. The corresponding U-values were 0.085 W/m^2K for outer walls and 0.075 W/m^2K for roof. The calculation results of passive level renovation of walls and roof for single buildings is presented in Appendix A.

The window renovation of this study means that heating energy use was calculated for all building types with passive level U-value of 0.7 W/m^2K for windows. The air-tightness n50 was estimated to be improved from 4 to 3 for detached and attached houses, and from 2.5 to 2.0 for blocks of flats. The calculation results are presented in Appendix A.

In the ventilation renovation, the heating energy use was calculated for all building types with an improved ventilation system. Exemplary buildings before 1980 had a natural ventilation system, buildings between 1980 and 1999 had a mechanical exhaust ventilation system and buildings after 2000 had a mechanical supply and exhaust system with the yearly heat recovery efficiency of 50%. All ventilation systems were improved to a level of a mechanical supply and exhaust system with the yearly heat recovery efficiency of 75%. The improved ventilation system fans had the energy class A (1.6 $kW/(m^3/s)$). The calculation results of renovation of ventilation system for single buildings are presented in Appendix A.

Solar heat installation means here that the heating energy use was calculated for all building types with a solar heating system to heat service water. Solar heating was estimated to cover 50% of the annual service water heating demand. The calculation results of utilizing solar heating for single buildings are presented in Appendix A.

A combination of these renovations means that all of the above renovations were applied.

10.4.2 Theoretical saving potential of renovations in Finnish housing stock

Calculation of the renovation cases show, that the combination of renovations is most effective, in terms of savings potential. This renovation type can lead up to 52% savings in energy consumption of residential buildings. This renovation type is followed by passive level envelopes, where the savings potential is 31%, and by ventilation renovation with savings potential of 12%. The saving potential of window renovation (8%) and solar heat installation (6%) are the least effective renovation methods of these under study.

Table 69. Energy consumption of buildings, the building stock of 2010 compared with scenarios where different energy renovation methods are applied to the whole building stock.

	Energy for space heating			Energy for electricity use			Total energy use		
	Total TWh	Saving TWh	Saving %	Total TWh	Saving TWh	Saving %	Total TWh	Saving TWh	Saving %
2010 situation	51.012	0	0	10.207	0	0	61.219	0	0
Passive-level envelope	31.840	19.172	38%	10.207	0	0%	42.047	19.172	31%
Ventilation renovation	43.259	7.753	15%	10.722	-0.515	-5%	53.981	7.238	12%
Solar heat installation	47.371	3.641	7%	10.252	-0.045	0%	57.623	3.596	6%
Window renovation	45.809	5.203	10%	10.273	-0.066	-1%	56.082	5.137	8%
Renovation combination	18.854	32.158	63%	10.775	-0.568	-6%	29.629	31.590	52%

Table 70. CO_2-equ emissions of buildings, the building stock of 2010 compared with scenarios where different energy renovation methods are applied to the whole building stock.

	CO_2-equ from heating			CO_2-equ from electricity use			Total CO_2-equ emissions		
	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %
2010 situation	10.686	0	0	2.289	0	0	12.975	0	0
Passive level envelope	6.814	3.872	36%	2.289	0	0%	9.103	3.872	30%
Ventilation renovation	9.004	1.682	16%	2.404	-0.115	-5%	11.408	1.567	12%
Solar heat installation	9.869	0.817	8%	2.299	-0.010	0%	12.168	0.807	6%
Window renovation	9.589	1.097	10%	2.303	-0.014	-1%	11.892	1.083	8%
Renovation combination	4.045	6.641	62%	2.416	-0.127	-6%	6.461	6.514	50%

11. Energy- and CO_2-equ saving potential of the Finnish housing stock due to natural exit of buildings, renovations and changes in heating method

11.1 Introduction and summary of results

The residential building stock is not a static set of buildings, but the number of buildings evolves over time when older buildings exit the stock and new buildings enter it. The buildings of a building stock also undergo renovations, changing them over time.

When buildings exit the housing stock, it results in savings in heating energy and electricity consumption. This also results in a decrease in greenhouse gas emissions, assuming that the emissions for the different energy types remain unchanged over time. Buildings also undergo energy renovations, decreasing their energy consumption, and resulting GHG emissions. Finally, the heating method of buildings may be changed causing changes both in energy consumption and GHG emissions.

This Chapter presents estimates for number of buildings in the building stock 2030. It also discusses the number of buildings that need either light or thorough renovations. Background information used for this Chapter is presented in the appendices. The size reduction rates and renovation needs are based on research by Nippala et al. [2010].

According to 2010 statistics of energy use in Finland, the total end use of energy was 279 TWh. The results of this section show that the outgoing building stock can cut the energy need by 2030 by 7 TWh. This equals to about 2.5% of the end-use of energy in Finland. The energy renovations, if applied to all the buildings in renovation need (either light or through), can bring up to 15 TWh annual savings in energy consumption, which equals to 5% of the end-use of energy in Finland. If the heating method of detached houses would be changed from electric and oil heating to ground heat pump and wood heating, this would result in 7.1 TWh savings by 2030, or 2.5% of the end-use of energy of today.

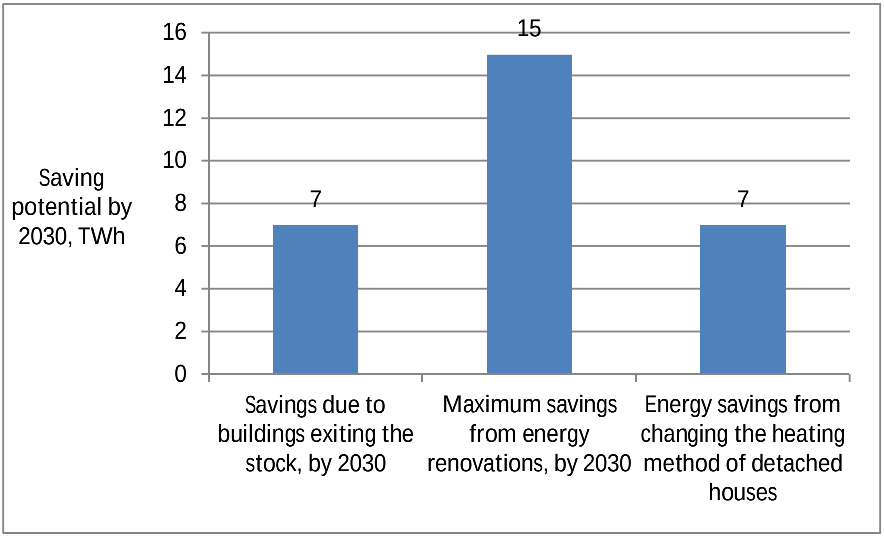


Figure 75. Saving potential of end-use of Energy in Finland for different factors. Annual savings in 2030 in TWh. Total end-use of energy in Finland in 2010 was 279 TWh.

The OECD data on Finnish GHG emissions show that the annual emissions in Finland in 2009 were 66 million tonnes (Mt). The outgoing building stock causes in a decrease of 2 Mt by 2030, equalling to about 2.5% of today's annual GHG emissions in Finland. Energy renovations, if applied to all buildings in need of thorough renovations, can bring up to 3.1 Mt annual savings in GHG emissions, equalling to 5% of country-scale emissions today. A simple study of changes in heating methods suggests that by changing heating methods of detached houses alone, could result in GHG savings of 4.3 Mt, or 6.5% of the current GHG emissions in Finland.

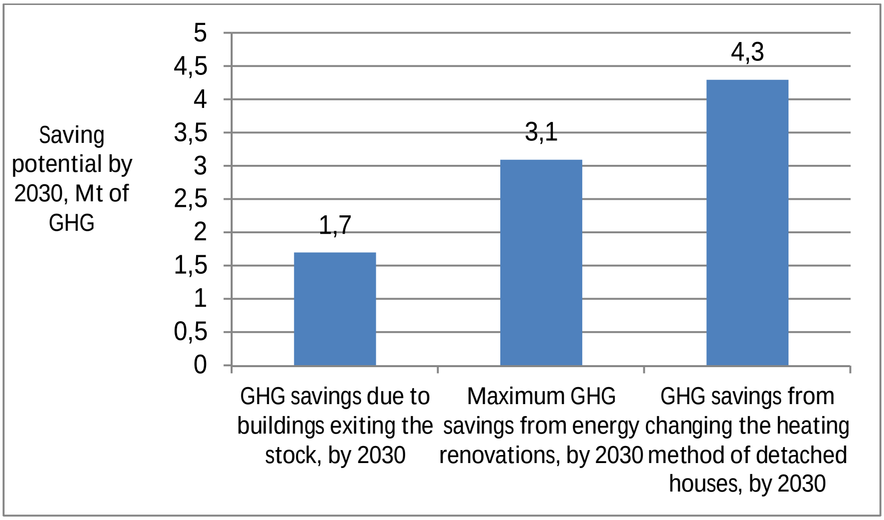


Figure 76. Saving potential of GHG emissions in Finland for different factors. Annual savings in 2030 in Mt. Total GHGs in Finland in 2009 was 66 Mt.

It is essential to note that while old buildings exit the building stock, new buildings enter it, replacing them. Therefore, the saving potential shown in this section will only be truly realized if the new buildings are highly energy efficient. In other words, only if all the buildings exiting the stock would be replaced with buildings consuming zero energy, or causing zero GHG emissions, the full saving potential presented here could be obtained. Since this is not realistic scenario in the near future, the saving potential of outgoing share of the building stock is decreased from that presented here.

The renovation scenarios may bring up to 5% savings in GHG emissions on country-level. However, this will require that all the buildings in need of thorough renovations will undergo ambitious energy renovations.

The potential of GHG emission savings by changing the heating method of detached houses, have 40% bigger GHG savings potential than ambitious energy renovations. The result suggests that the future renovations should not only focus on improving energy efficiency of buildings, but should also consider the heating methods.

Summary of the results (presented more in detail in Section 11.2 and 11.3)

The calculations of the previous Chapter showed that the annual total energy consumption of Finnish residential housing stock equals to 51 TWh, as in 2010. The calculations of this Chapter show that that the outgoing buildings of the stock decrease the annual total energy consumption by 2.2 TWh by 2020 and by 6.8 TWh by 2030. This means that the annual total energy consumption of the residential housing stock of 2010 would equal to 44 TWh in 2030, due to outgoing share of building stock, assuming that the energy consumption of single buildings would remain unchanged over time.

The results suggest that the outgoing share of building stock corresponds to GHG savings of 0.5 Mt by 2020 and 1.7 Mt by 2030.

However, energy renovations will take place over time. The other part of this Chapter shows that if all the buildings in need of thorough renovations could be renovated to consume zero energy, the annual total energy consumption of residential buildings would fall to 24.5 TWh by 2030. When this is compared to the total energy consumption of the un-renovated case in 2030 (44 TWh), a maximum energy saving potential of renovations in the housing stock can be estimated to be roughly 28.5 TWh.

However, renovations to zero-energy consumption are not realistic or feasible in most cases. Therefore this study calculates the energy saving potential of some realistic renovation alternatives.

The saving potential of five different renovations is calculated, by assuming that all the buildings that face the renovation need will be renovated with one of them. The renovations are divided into thorough and light renovations. It is considered that installing passive level windows is a light renovation, while passive level building envelope renovation, ventilation renovation, solar heat installation, and a combination of all the four renovations are thorough renovations.

The results show that the installation of passive level windows to all buildings needing light renovation would result in 2.4 TWh energy savings on stock-level. The results for thorough renovations show that a combination of renovations could bring up to 15 TWh savings in annual total energy consumption, whereas passive level envelope renovations would equal to 9.3 TWh, ventilation renovation to 3.3 TWh and solar heat installation to 1.5 TWh annual savings in total energy consumption.

The results show that the installation of passive level windows to all the buildings in light renovation need would result in 0.5 million tonnes (Mt) of GHG savings on stock-level by 2030. The results for thorough renovations show that a combination of renovations could bring up to 3.1 Mt savings in annual GHG emissions, whereas passive level envelope renovations would equal to 1.9 Mt, ventilation renovation to 0.7 Mt and solar heat installation to 0.3 Mt of annual savings in GHG emissions.

Changes in the heating method are studied for two different cases. The calculation results show that if all the detached houses with electrical heating were converted to ground heating, and all the houses with oil-heating would be converted to wood heating, the energy annual total energy need would decrease by 7.1 TWh. This would result in annual GHG emission savings of 4.3 Mt.

The GHG calculations were done on the bases the characteristic values given in Chapter 3. The average value of year 2008 calculated with benefit distribution method was used for electricity and district heat. As stated earlier the selection of the starting values significantly affects the results. The effect of the change of heating system may also be assessed with using marginal values. For example if the

11.2 The development of the size of Finnish housing stock by 2020 and 2030

This Section presents a forecast for the development of the housing stock of 2010, from 2010 until 2030.

The assessed total number of detached houses in 2010 was 1.1 million buildings. Some 56000 buildings (5%) are expected to exit the building stock by 2020 and 162000 buildings (15%) by 2030. The following Figure illustrates the development in the total number of detached houses of 2010, by 2020 and 2030.

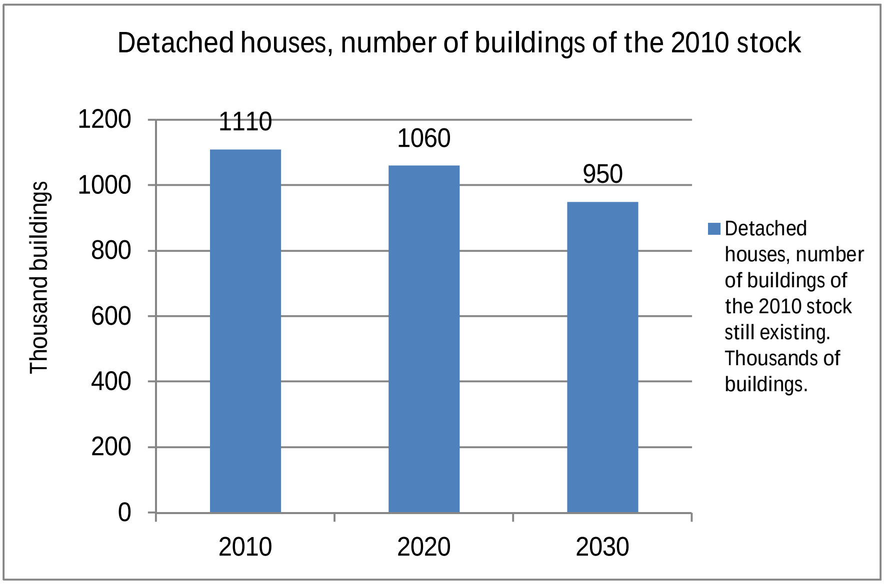


Figure 77. Number of buildings of the 2010 building stock still existing in years 2020 and 2030. Detached houses. Unit: thousands of buildings.

The share of outgoing building stock will not be constant between different age-groups, but will vary. The following Figure and table show information about the size development due to outgoing share of buildings on age-group-level. More detailed information about number of buildings can be found in Appendix C.

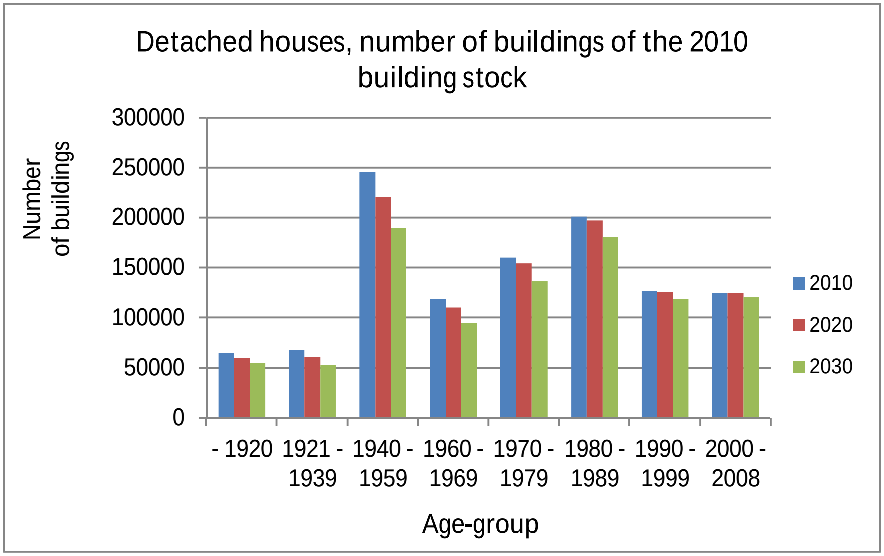


Figure 78. Number of detached houses of 2010. Estimates for number of buildings in different age-groups in 2010, 2020 and 2030. Figure from Mecoren-tool.

Table 71. Number of detached houses of 2010. Estimates for number of buildings in different age-groups in 2010, 2020 and 2030.

Detached houses, number of buildings			
Building year	2010	2020	2030
–1920	65095	59895	54831
1921–1939	68275	61392	52741
1940–1959	246056	221430	190134
1960–1969	118979	110339	95391
1970–1979	160611	154423	137083
1980–1989	201544	197479	181004
1990–1999	126860	126183	118884
2000–2008	125132	125132	120756
Sum	1112600	1056300	950800

The total energy consumption was calculated with Mecoren tool. The total energy consumption for detached houses in 2010 was 37 TWh, of which 31 TWh was heating energy and 6 TWh electricity use. It was assumed that if a building is to exit the building stock before 2030, it shall not undergo any energy renovations before that. The energy saving estimates could then be calculated by keeping energy consumption per building constant, and altering the number of buildings.

The energy consumption calculations for detached houses show that the decreasing number of buildings will result in a decreased amount of total energy (amount of heating energy and electricity combined) needed. The total energy need of detached houses will fall by 2 TWh (to 35 TWh) by 2020 and by 7 TWh (to 32 TWh) by 2030.

Table 72. Annual heating energy and electricity use of all detached houses in Finland. Energy use, as in 2010, and estimated energy use after a certain amount of buildings exit the building stock by 2020 and 2030. Unit: GWh.

Total energy use of detached houses			
	Heating energy use (TWh)	Electricity use (TWh)	Total heating energy use (TWh)
2010	31.000	6.300	37.300
2020	29.400	6.000	35.400
2030	26.400	5.400	31.800

The following table shows that the annual GHG-emissions of detached houses will fall 400 thousand tonnes by 2020, and by 1100 thousand tonnes by 2030, due to decrease in the amount of buildings.

Table 73. Annual GHG-emissions from energy use of all detached houses in Finland. GHG-emissions, as in 2010, and estimated emissions after a certain amount of buildings exit the building stock by 2020 and 2030. Unit: thousand tonnes of CO2-equ.

Total GHG-emissions of detached houses			
	Emissions from heating energy use (Thousands of tonnes, Mt)	Emissions from Electricity use (Thousands of tonnes, Mt)	Total emissions (Mt)
2010	6.100	1.400	7.500
2020	5.800	1.300	7.100
2030	5.200	1.200	6.400

The total number of attached houses in 2010 was 74900 buildings. Some 2500 buildings (4%) are expected to exit the building stock by 2020 and 8500 buildings (13%) by 2030. The following figure illustrates the development in the total amount of attached houses of 2010, by 2020 and 2030.

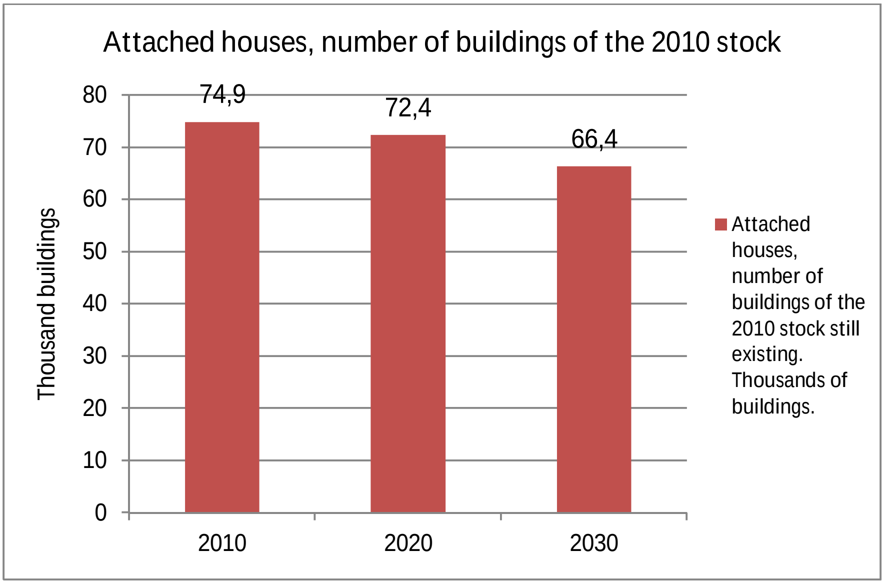


Figure 79. Number of buildings of the 2010 building stock still existing in years 2020 and 2030. Attached houses. Unit: thousands of buildings.

The following figure and table show information about the size development of attached houses, due to outgoing share of buildings. The information is given at age-group-level. More detailed information about number of buildings can be found in Appendix C.

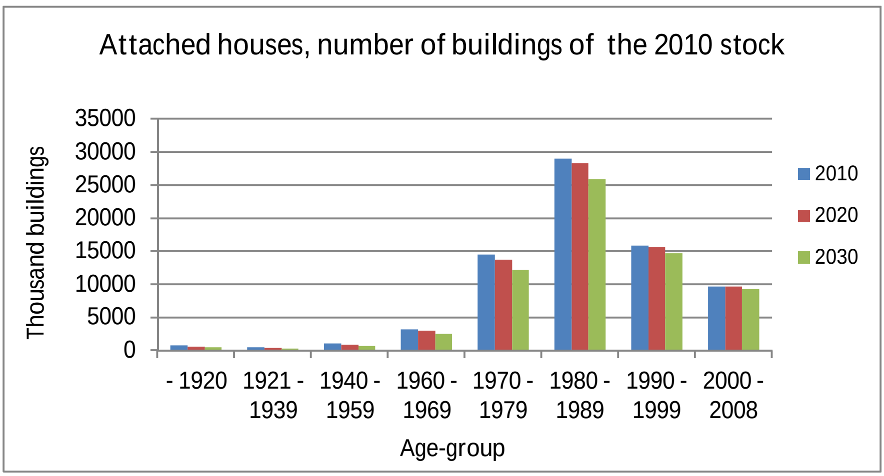


Figure 80. Number of attached houses of 2010. Estimates for number of buildings in different age-groups in 2010, 2020 and 2030. Figure from Mecoren-tool.

Table 74. Number of attached houses of 2010. Estimates for number of buildings in different age-groups in 2010, 2020 and 2030.

Attached houses, ,number of buildings			
Building year	2010	2020	2030
–1920	764	609	538
1921–1939	501	394	322
1940–1959	1095	876	744
1960–1969	3275	3015	2594
1970–1979	14551	13810	12216
1980–1989	29091	28363	25954
1990–1999	15904	15668	14725
2000–2008	9674	9674	9306
Sum	74900	72400	66400

The total energy consumption was calculated with Mecoren tool. The total energy consumption for attached houses in 2010 was 6.7 TWh, of which 5.5 TWh was heating energy and 1.2 TWh electricity use.

The energy consumption calculations for attached houses show that the decreasing number of buildings will result in a decreased amount of total energy demand. The total energy demand of attached houses will fall by 0.2 TWh (to 6.5 TWh) by 2020, and by 0.8 TWh (to 5.9 TWh) by 2030.

Table 75. Annual heating energy and electricity use of all attached houses in Finland. Energy use, as in 2010, and estimated energy use after a certain amount of buildings exit the building stock by 2020 and 2030.

Total energy use of attached houses			
	Heating energy use (TWh)	Electricity use (TWh)	Total heating energy use (TWh)
2010	5.500	1.200	6.700
2020	5.300	1.200	6.500
2030	4.800	1.100	5.900

The following table shows that the annual GHG-emissions of attached houses will decrease by 0.060 Mt by 2020, and by 0.200 Mt by 2030, due to decrease in the number of buildings.

Table 76. Annual GHG-emissions from energy use of all attached houses in Finland. GHG-emissions, as in 2010, and estimated emissions after a certain amount of buildings exit the building stock by 2020 and 2030. Unit: thousand tonnes of CO2-equ.

Total GHG-emissions of detached houses			
	Emissions from heating energy use (Thousands of tonnes, tt)	Emissions from Electricity use (Thousands of tonnes, tt)	Total emissions (Thousands of tonnes, tt)
2010	1350	280	1630
2020	1300	270	1570
2030	1180	240	1430

The total number of residential blocks of flats in 2010 was 55900 buildings. Some 1300 buildings (2%) are expected to exit the building stock by 2020 and 2500 buildings (8%) by 2030. The following figure illustrates the development in the total amount of attached houses of 2010, by 2020 and 2030.

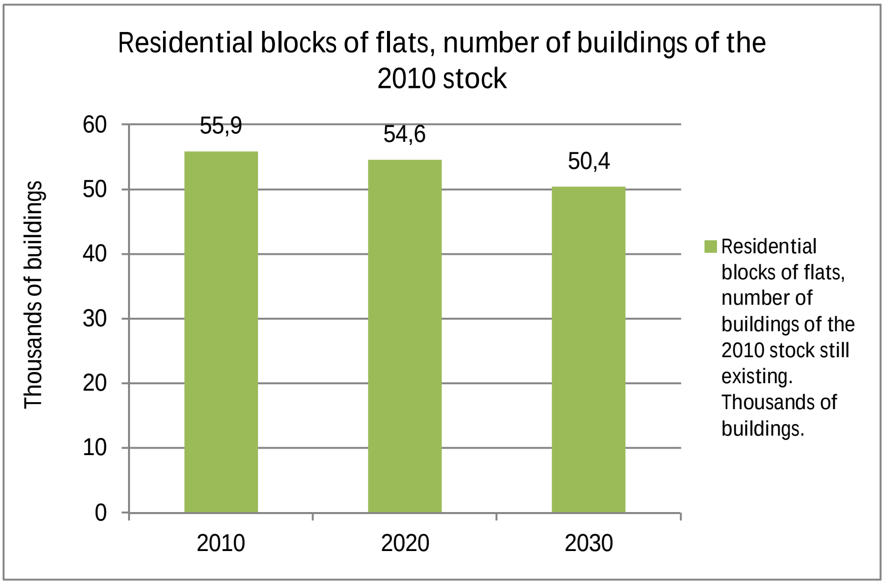


Figure 81. Number of buildings of the 2010 building stock still existing in years 2020 and 2030. Residential blocks of flats. Unit: thousands of buildings.

The following figure and table show information about the size development of residential blocks of flats, due to outgoing share of buildings. The information is given at age-group-level. More detailed information about number of buildings can be found in Appendix C.

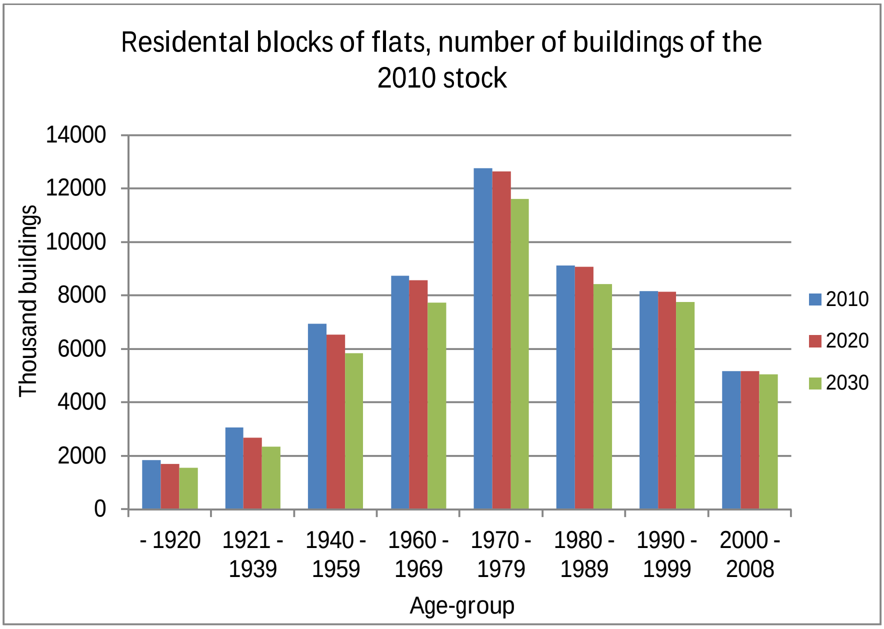


Figure 82. Number of residential blocks of flats of 2010. Estimates for number of buildings in different age-groups in 2010, 2020 and 2030. Figure from Mecoren-tool.

Table 77. Number of residential blocks of flats of 2010. Estimates for number of buildings in different age-groups in 2010, 2020 and 2030.

Residential blocks of flats, number of buildings			
Building year	2010	2020	2030
–1920	1840	1709	1571
1921–1939	3072	2684	2355
1940–1959	6952	6551	5852
1960–1969	8752	8579	7745
1970–1979	12773	12641	11618
1980–1989	9132	9087	8427
1990–1999	8178	8139	7756
2000–2008	5176	5176	5065
Sum	55900	54600	50400

The total energy consumption was calculated with Mecoren tool. The total energy consumption for residential blocks of flats in 2010 was 17.2 TWh, of which 14.5 TWh was heating energy and 2.7 TWh electricity use.

The energy consumption calculations for residential blocks of flats show that the decreasing number of buildings will result in a decreased amount of total energy demand. The total energy need of residential blocks of flats will fall by 0.4 TWh (to 16.8 TWh) by 2020, and by 1.8 TWh (to 15.4 TWh) by 2030. In other words, the exit of residential blocks of flats will result in annual energy savings of about 0.8 TWh by 2030. The following table shows more detailed results.

Table 78. Annual heating energy and electricity use of all residential blocks of flats in Finland. Energy use, as in 2010, and estimated energy use after a certain amount of buildings exit the building stock by 2020 and 2030.

Total energy use of residential blocks of flats			
	Heating energy use (TWh)	Electricity use (TWh)	Total heating energy use (TWh)
2010	14.500	2.700	17.200
2020	14.100	2.700	16.800
2030	13.000	2.500	15.400

The following table shows that the annual GHG-emissions of residential blocks of flats will fall by 90 thousand tonnes by 2020, and by 390 thousand tonnes by 2030, due to decrease in the amount of buildings.

Table 79. Annual GHG-emissions from energy use of all residential blocks of flats in Finland. GHG-emissions, as in 2010, and estimated emissions after a certain amount of buildings exit the building stock by 2020 and 2030. Unit: thousand tonnes of CO_2-equ.

Total CO_2-emissions of residential blocks of flats			
	Emissions from heating energy use (Mt)	Emissions from Electricity use (Mt)	Total emissions (Mt)
2010	3.280	0.610	3.890
2020	3.200	0.590	3.800
2030	2.950	0.550	3.500

11.3 Realistic renovation need of residential buildings of 2010 by 2020 and 2030, and the associated energy saving potential

This section presents estimates about the renovation needs of the remaining stock part and analyses the energy-saving potential of renovations. The Mecoren-tool was used in calculations to analyse the effect of a set of different renovations.

The actual renovation need is in significant role in energy renovations, since the energy renovations are rarely feasible, if done solely on energy-saving basis. The energy renovations are mostly done according to the buildings' normal refurbishment cycles. This section looks into the renovation needs of the Finnish residential housing stock, and estimates the maximum saving potential for the energy renovations, focusing on the buildings in renovation need.

The renovations are divided into light and thorough renovations. Thorough renovations are considered to be large-scale renovations, in which the building needs to be emptied so that the renovation activities can take place, whereas light renovations are renovations with only minimal distortion to the inhabitants. It was assumed that those buildings, which undergo light or thorough renovations between 2010 and 2030 remain in the housing stock in 2030. Renovations are not done on buildings, which are about to exit the building stock in the near future.

This section assumes that all the buildings with the renovation need will be renovated. It is estimated that by 2030, 45…60% of the building stock of 2010 will need thorough renovations, and 50…60% of it will need light renovations. The renovation estimates vary by building type and building age. The following two tables show the estimated number of detached and attached houses, and residential blocks of flats in need of light and thorough renovations by 2030.

Table 80. Predicted need of thorough renovations in the residential housing stock of 2010. Number of buildings in need of thorough renovations between years 2010 and 2030.

Predicted refurbishment need, no. of buildings in need of thorough renovations			
Building year	Detached houses	Attached houses	Residential blocks of flats
–1920	28000	310	730
1921–1939	30950	200	1190
1940–1959	127840	410	2850
1960–1969	69460	1300	3720
1970–1979	93420	5870	6620
1980–1989	115010	11890	5210
1990–1999	55660	8090	2760
2000–2008	25030	1930	520
	545400	30000	23600

Table 81. Predicted need of light renovations in the residential housing stock of 2010. Number of buildings in need of light renovations between years 2010 and 2030.

Predicted refurbishment need, no. of buildings in need of light renovations			
Building year	Detached houses	Attached houses	Residential blocks of flats
–1920	34500	380	1040
1921–1939	33880	250	1690
1940–1959	105910	580	3900
1960–1969	45190	1840	4950
1970–1979	64090	8310	6090
1980–1989	84500	16840	3900
1990–1999	70870	7700	5400
2000–2008	50050	3870	2330
	489000	39770	29300

If all of the buildings in thorough renovation need could be renovated to zero-energy-level so that they would consume no energy at all, the total energy consumption of the Finnish building stock would equal to 24.5 TWh annually, resulting in 5.3 Mt of GHG emissions. However, renovations to zero-energy consumption are not realistic or feasible in most of the cases. Therefore this study calculates the energy saving potential of some realistic renovation alternatives.

Effectiveness of different energy renovations, in terms of total energy consumption

The saving potential of five different renovations is calculated, by assuming that all the buildings which come to renovation need will be renovated with one of them. The renovations are divided into thorough and light renovations. It is considered that installing passive level windows is a light renovation, and passive level building envelope renovation, ventilation renovation, solar heat installation, and a combination of all the four renovations are thorough renovations.

All the calculations were made with Mecoren-tool by assuming that all the buildings that will come to renovation need between 2010 and 2030 will be renovated with a single renovation method, and combining the results together.

The results show that the installation of passive level windows to all the buildings in light renovation need would result in 2.4 TWh energy savings on stock-level. The results for thorough renovations show that a combination of renovations could bring up to 15 TWh savings in annual total energy consumption, whereas passive level envelope renovations would equal to 9.3 TWh, ventilation renovation to 3.3 TWh and solar heat installation to 1.5 TWh annual savings in total energy consumption.

The following table summarizes the results on stock scale. The table presents the energy consumption of the building stock in 2030, as it would be without energy renovations. The base case is then compared with the energy consumption of alternative renovation scenarios, resulting in figures for total energy savings for different renovation activities.

The following table shows that the energy saving potential of different renovation alternatives ranges from 3% (solar heat installation) to 28% (a combination of renovations). More comprehensive result tables are presented in the appendices, showing similar tables for all the different building types, and for years 2020 and 2030.

The results for individual building types also pointed out that the most effective renovation methods for detached and attached houses are passive level envelope renovations, and a combination of multiple renovations. For the residential blocks of flats, the results suggest that passive level envelopes, ventilation renovation and a combination of renovations are the three most effective renovations.

Table 82. Energy consumption of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildings in renovation need have been renovated with a certain renovation method. Results are for all residential buildings, and the year under consideration is 2030.

	Energy for space heating			Energy for electricity use			Total energy use		
	Total TWh	Saving TWh	Saving %	Total TWh	Saving TWh	Saving %	Total TWh	Saving TWh	Saving %
2030, no energy renovations	44.213	0	0	8.915	0	0	53.128	0	0
Passive-level envelope	34.919	9.294	21%	8.915	0	0%	43.834	9.294	17%
Ventilation renovation	40.572	3.641	8%	9.212	-0.297	-3%	49.784	3.344	6%
Solar heat installation	42.660	1.553	4%	8.937	-0.022	0%	51.597	1.531	3%
Window renovation	41.746	2.467	6%	8.947	-0.032	0%	50.693	2.435	5%
Renovation combination	28.828	15.385	35%	9.240	-0.325	-4%	38.068	15.060	28%

Effectiveness of different energy renovations, in terms of GHG emissions

The calculations were made with the Mecoren-tool. The tool calculates the GHG emissions, based on total amount of emissions by energy type, and specific environmental profiles for each of these energy types.

The results show that the installation of passive level windows to all the buildings in light renovation need would result in 0.5 million tonnes (Mt) of GHG savings on stock-level by 2030. The results for thorough renovations show that a combination of renovations could bring up to 3.1 Mt savings in annual GHG emissions, whereas passive level envelope renovations would equal to 1.9 Mt, ventilation renovation to 0.7 Mt and solar heat installation to 0.3 Mt of annual savings in GHG emissions.

The following table shows that the energy saving potential of different renovation alternatives ranges from 3% (solar heat installation) to 27% (a combination of renovations). More comprehensive result tables are presented in the appendices, showing similar tables for all the different building types, and for years 2020 and 2030.

Table 83. GHG-emissions of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildings in renovation need have been renovated with a certain renovation method. Results are for all residential buildings, year of consideration is 2030.

	CO2-equ emissions from heating			CO2-equ emissions, electricity use			Total CO2-equ emissions		
	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %
2030, no energy renovations	9.30	0	0%	2.00	0	0%	11.30	0	0%
Passive-level envelope	7.43	1.88	20%	2.00	0	0%	9.43	1.88	17%
Ventilation renovation	8.52	0.79	8%	2.07	-0.07	-3%	10.59	0.72	6%
Solar heat installation	8.96	0.35	4%	2.00	-0.01	0%	10.96	0.34	3%
Window renovation	8.78	0.52	6%	2.01	-0.01	0%	10.79	0.51	5%
Renovation combination	6.13	3.17	34%	2.07	-0.07	-4%	8.21	3.10	27%

Effectiveness of change in the heating method, in terms of energy consumption and GHG emissions

In addition to energy renovations, buildings may also undergo renovations related to their heating systems. This study looks detached houses, since changes in their heating systems are relatively easy to implement, and, for example conversions from electrical heating to geothermal heating has already become quite popular.

This section studies the effects on total energy consumption and GHG emissions, if all the detached houses with electric heating and oil-heating would change their heating method by 2030. The calculations in this chapter were made with Mecoren-tool. In the first calculation case, it was assumed that all the detached houses with electric heating would be converted to use geothermal heating by 2030. In the second calculation scenario, all the detached houses with oil-heating are expected to change to use wood heating by 2030. The share of other heating methods is expected to stay unchanged.

The most common heating method in detached houses is electrical heating. As stated in earlier chapters, the amount of detached houses is expected to be at the level of 950000 buildings in 2030. 43% of the detached houses outgoing from stock are heated with electrical heating, followed by oil-heating (28%) and wood heating (21%).

The following figure illustrates the situation in 2030, if no changes in heating methods take place.

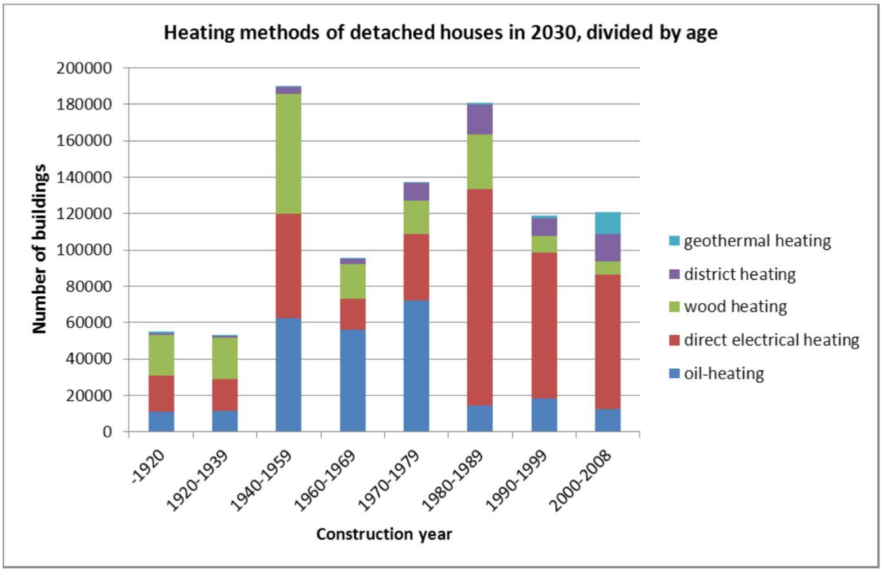


Figure 83. Heating methods of detached houses. Number of buildings with different heating methods in 2030. Figure from Mecoren-tool.

As earlier chapters stated, the energy consumption of detached houses, if left without energy renovations, would equal to 32 TWh in 2030, resulting in GHG emissions of 6.4Mt.

The calculation results show that if all the detached houses with electrical heating were converted to ground heating, the total energy consumption of detached houses would fall to 23 TWh, resulting in GHG emissions of 4.6 Mt. The corresponding savings, compared to baseline case, would equal to 8.6 TWh, and 1.8 Mt of GHGs.

If all the detached houses with oil heating would be converted to wood heating, the total energy need would rise (due to inefficiencies in wood heating systems) to 33 TWh. However, the GHG emissions would drop to 3.8 Mt, due to the more favourable environmental profile of wood-heating. The increase in energy consumption, compared to baseline case equals to 1.5 TWh, and savings in GHG emissions to 2.6 Mt.

If both of the changes in heating methods would happen, the total energy need would fall to 25 TWh, and the GHG emissions to 2.1 Mt. The results are presented in the following two tables. These equal to savings of 7.1 TWh and 4.3 Mt of GHG.

Table 84. Effect of the assumed change on heating method in energy use.

	Energy for space heating			Energy for electricity use			Total energy use		
	Total TWh	Saving TWh	Saving %	Total TWh	Saving TWh	Saving %	Total TWh	Saving TWh	Saving %
2030, no energy renovations	26.388	-	-	5.370	-	-	31.758	-	-
2030, electric heating changed to ground heating	19.367	7.021	27%	3.800	1.570	29%	23.167	8.591	27%
2030, oil heating changed to wood heating	27.951	-1.563	-6%	5.341	0.029	1%	33.292	-1.534	-5%
2030, electric heating changed to ground heating, and oil heating changed to wood heating	20.930	5.458	21%	3.771	1.599	30%	24.700	7.058	22%

Table 85. Effect of the assumed change in heating method on GHGs.

	CO2-equ heating			CO2-equ electricity use			Total CO2-equ emissions		
	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %
2030, no energy renovations	5.169	-	-	1.204	-	-	6.373	-	-
2030, electric heating changed to ground heating	3.721	1.448	28%	0.852	0.352	29%	4.573	1.800	28%
2030, oil heating changed to wood heating	2.718	2.451	47%	1.198	6	1%	3.916	2.457	39%
2030, electric heating changed to ground heating, and oil heating changed to wood heating	1.270	3.899	75%	0.845	0.359	30%	2.116	4.257	67%

To sum things up, the change in heating methods may not necessarily cause energy savings, but it may lead to significant GHG emission savings. If all the detached houses with electrical heating would change their heating method to ground heating, and all houses with oil-heating to wood heating, estimated GHG savings would equal to about 4.3 Mt, or 67%, compared to the baseline case.

12. Potential of selected refurbishment actions

This chapter analyses the energy saving and GHG emissions savings potential of selected renovation actions. The buildings analysed here are detached houses, built between 1940–1959 and between 1980–1989, and residential blocks of flats built between 1960–1969 and 1970–1979.

The buildings analysed here are selected due to their large importance on the total energy consumption of the Finnish residential building stock. The energy consumption (heating energy and electricity) of these four building types account for about 24 TWh, which equals to 39% of the total energy consumption of the Finnish residential housing stock in 2010. The GHG emissions of these four building types is 5 Mt, equalling to 36% of the emissions of the housing stock in 2010.

On country-scale, these buildings are accountable for 9% of end-use of energy in Finland and for 8% of Finland's GHG emissions.

It was earlier found that the most effective single renovation methods for detached houses is passive level envelope and for residential blocks of flats ventilation renovation and passive level envelope. These and a combination of different renovations are analysed in this section.

The calculations are made for years 2020 and 2030, in terms of energy consumption and CO_2-equ emissions.

These calculations make the assumption that the energy renovations are feasible, and thus, done only during the normal renovation cycles of buildings. Passive level envelope renovations, installation of new ventilation systems and a combination of renovations are large-scale renovations. Therefore it is assumed that they can be done only, when the buildings are in need of thorough renovations.

This study makes the assumption that future building and energy regulations will raise the rate of energy renovations, by making them mandatory when thorough renovations take place. The baseline scenario assumes that buildings in need of thorough renovations will be obliged to increase their energy effectiveness when renovated after year 2015. The baseline scenario assumes that all buildings in thorough renovation need will be obliged to add 100mm of thermal insulation, after year 2015. Until then, it is assumed, that no energy renovations will take place.

12.1 Estimated savings in energy consumption and CO2-equ emissions, due to refurbishment of detached houses built between 1940 and 1959

The average detached house of 1940–1959 is a one-floor building with a floor area of 105 m^2 and a volume of 330 m^3. These buildings house on average two inhabitants and their total number in Finnish residential housing stock equals to 246000 buildings, in 2010. The surface areas for this type of building are, for external walls 121m^2, roof and base floor 107 m^2, and for windows 10 m^2. The total floor area of this building type equals to 26.3 million square meters.

The annual heating energy consumption for this building type is 29800 kWh/a, the annual electricity use 5400 kWh/a, and CO2-equ emissions 6 tonnes per building.

The energy consumption (heating energy and electricity) of detached houses built between 1940–1959 account for about 8.7 TWh, in 2010. This equals to 14% of the total energy consumption of the Finnish residential housing stock in 2010. The CO_2-equ emissions of these buildings are 1.5 Mt, equalling to 12% of the emissions of the Finnish residential housing stock in 2010.

On country-scale, these buildings are accountable for 3% of total energy consumption in Finland (279TWh), and for 2% of total CO2-equ emissions (66 Mt).

Number of buildings to be renovated between 2013 and 2030

The size of the building stock develops over time, as discussed earlier in this research. This calculation takes into account the reduction in the number of buildings by assuming that the number of the buildings will fall from 246000 pcs of 2010 to 190000 pcs by 2030. The total floor area of this building type is estimated to be 20.3 million square meters in 2030.

As presented earlier in this research, the estimated renovation need of this building type is 127800 pcs from 2010 until 2030. Since the period of this study is 2013–2030, the renovation figure needs to be adjusted. This is done by deducting renovations done between 2010 and 2012, from the original renovation estimate. This results in an estimated number of 109600 buildings need to be renovated between 2010 and 2030, equalling to 11.7 million square meters. This means that about 58% of the buildings of this building type, which exist in 2030, will need thorough renovations between 2013 and 2030.

The following table presents the energy consumption of this building type, as in 2010 without renovation, and after selected renovation activities.

Table 86. Energy consumption of a single building, before and after different renovations, detached houses, 1940–1959.

	Heating energy consumption		Electricity consumption	
Detached houses, 1940–1959	MWh/a/building	MWh/a /m2	MWh/a/building	MWh/a /m2
Building, as in 2010	29.8	0.279	5.4	0.051
Renovated with 100mm thermal insulation	20.4	0.191	5.4	0.051
Renovated with 100mm thermal insulation and ventilation renovation	19.5	0.183	5.9	0.055
Renovated with passive level envelope	11.6	0.109	5.4	0.051
Renovated with a combination of renovations	7.6	0.072	6.0	0.056

Renovation scenarios

This study analyses the effects of renovations by scenario analyses. The baseline scenario, which is made to match expected renovation trends, is compared to an alternative scenario with more advanced renovation methods.

The baseline scenario assumes that by 2015, new building and energy regulations will come in place, making energy renovations mandatory when thorough renovations take place. The baseline scenario assumes that no energy renovations take place between 2013 and 2015. From 2015 onwards, 75% of all buildings in need of thorough renovations shall be renovated with 100mm thick additional thermal insulation, and 25% of them with 100mm thermal insulation and a ventilation renovation.

In other words, baseline scenario assumes that by 2030, a total number of 190000 buildings exist, from which 98700 pcs are without energy renovations, 68500pcs with 100mm additional thermal insulation, and 22800 pcs with 100mm additional thermal insulation and ventilation renovation.

Table 87. Number and floor area of buildings with different renovations in 2030, baseline scenario.

	pcs	million m^2
Total number of buildings in 2030	190000	20.3
No energy renovations	98700	10.5
100mm additional thermal insulation	68500	7.3
100mm additional thermal insulation and ventilation renovation	22800	2.4

The alternative scenario assumes that new building and energy regulations will come in place in a faster schedule, already in 2013. Energy renovations are assumed to be mandatory when thorough renovations take place. The alternative scenario assumes that from 2013 onwards, 50% of all buildings in need of thorough renovations shall be renovated with passive level additional thermal insulation, and another 50% with a combination of renovations, where envelope, window, ventilation and solar heat installation takes place. In other words, the alternative scenario assumes that by 2030, a total number of 190000 buildings exist, from which 80400 pcs are without energy renovations, 54800 pcs with passive level envelope and 57500 pcs with a combination of renovations.

Table 88. Number and floor area of buildings with different renovations in 2030, alternative scenario.

	pcs	million m^2
Total number of buildings in 2030	190000	20.3
No energy renovations	98700	10.5
Passive-level envelope renovation	45650	4.9
A combination of renovations	45650	4.9

Results for saving potential of renovations

The following table shows saving potential for different calculation scenarios. If the renovations would be made according to baseline scenario, the savings would equal to 0.9 TWh by 2030, in terms of total energy. For alternative scenario, the savings would be 1.8 TWh.

When these are compared to the total energy consumption in Finland (279 TWh), it shows that the saving potential of baseline scenario equals to 0,3% savings, and saving potential of alternative scenario equals to 0,6% of energy country-scale energy-consumption.

Table 89. Saving potential of renovation scenarios, no renovations compared with baseline, and alternative scenarios, annual energy consumption of all the buildings of this building type in 2030.

	Heating energy			Electricity			Total energy		
	GWh/a, all buildings	Savings GWh/a	Savings %	GWh/a, all buildings	Savings GWh/a	Savings %	GWh/a, all buildings	Savings GWh/a	Savings %
Build-ings, as in 2010	5662	0	-	1026	0	-	6688	0	-
Renova-tions as in base-line scenario	4783	879	16%	1039	-13	-1%	5822	866	13%
Renova-tions as in alter-native scenario	3818	1844	33%	1053	-27	-3%	4871	1817	27%

12.2 Estimated savings in energy consumption and CO2-equ emissions, due to refurbishment of detached houses built between 1980 and 1989

The average detached house of 1980–1989 is a one-floor building with a floor area of 148 m^2 and a volume of 475 m^3. These buildings house on average three inhabitants and their total number in Finnish residential housing stock equals to 202000 buildings, in 2010. The surface areas for this type of building are, for external walls 140 m^2, roof and base floor 148 m^2, and for windows 17 m^2. The total floor area of this building type equals to 29.7 million square meters.
The annual heating energy consumption for this building type is 28400 kWh/a, the annual electricity use 6000 kWh/a, and CO_2-equ emissions 5 tonnes per building.

The energy consumption (heating energy and electricity) of detached houses built between 1980–1989 accounts for about 6.9 TWh, in 2010. This equals to 11% of the total energy consumption of the Finnish residential housing stock in 2010. The CO2-equ emissions of this building type are 1.3 Mt, equalling to 10% of the emissions of the Finnish residential housing stock in 2010.

On country-scale, these buildings are accountable for 2% of total energy consumption in Finland (279 TWh), and for 2% of total CO_2-equ emissions (66 Mt).

Number of buildings to be renovated between 2013 and 2030

The size of the building stock develops over time, as discussed earlier in this research. This calculation takes into account the reduction in the number of buildings by assuming that the number of the buildings will fall from 202000 pcs of 2010 to 181000 pcs by 2030. The total floor area of this building type is estimated to be 26.7 million square meters in 2030.

As presented earlier in this research, the estimated renovation need of this building type is 115000 pcs from 2010 until 2030. Since the period of this study is 2013–2030, the renovation figure needs to be adjusted. This is done by deducting renovations done between 2010 and 2012, from the original renovation estimate. This results in that an estimated number of 98600 buildings need to be renovated between 2013 and 2030 equalling to 14.6 million square meters. This means that about 53% of the buildings of this building type, which exist in 2030, will need thorough renovations between 2013 and 2030. The following table presents the energy consumption of this building type, as in 2010 without renovation, and, after selected renovation activities.

Table 90. Energy consumption of a single building, before and after different renovations, detached houses, 1980–1989

	Heating energy consumption		Electricity consumption	
Detached houses, 1980–1989	MWh/a/ building	MWh/a/ m^2	MWh/a/ building	MWh/a/ m^2
Building, as in 2010	28.4	0.192	6.0	0.041
Renovated with 100mm thermal insulation	25.4	0.172	6.0	0.041
Renovated with 100mm thermal insulation and ventilation renovation	17.9	0.121	6.3	0.043
Renovated with passive level envelope	19.6	0.133	6.0	0.041
Renovated with a combination of renovations	9.6	0.065	6.4	0.043

Renovation scenarios

This study analyses the effects of renovations by scenario analyses. The baseline scenario, which is made to match expected renovation trends, is compared to an alternative scenario with more advanced renovation methods.

The baseline scenario assumes that by 2015, new building and energy regulations will come into force making energy renovations mandatory when thorough renovations take place. The baseline scenario assumes that no energy renovations take place between 2013 and 2015. From 2015 onwards, 75% of all buildings in need of thorough renovations shall be renovated with 100mm thick additional thermal insulation, and 25% of them with 100mm thermal insulation and a ventilation renovation.

In other words, baseline scenario assumes that by 2030, a total number of 181000 buildings exist, from which 98900 pcs are without energy renovations, 61600 pcs with 100mm additional thermal insulation, and 20500 pcs with 100mm additional thermal insulation and ventilation renovation.

Table 91. Number and floor area of buildings with different renovations in 2030, baseline scenario.

	pcs	million m^2
Total number of buildings in 2030	181000	26.7
No energy renovations	98900	14.6
100mm additional thermal insulation	61600	9.1
100mm additional thermal insulation and ventilation renovation	20500	3.0

The alternative scenario assumes that new building and energy regulations will come into force in a faster schedule, already in 2013. Energy renovations are assumed to be mandatory when thorough renovations take place. The alternative scenario assumes that from 2013 onwards, 50% of all buildings in need of thorough renovations shall be renovated with passive level additional thermal insulation, and another 50% with a combination of renovations, where envelope, window, ventilation and solar heat installation takes place.

In other words, the alternative scenario assumes that by 2030, a total number of 181000 buildings exist, from which 82400 pcs are without energy renovations, 49300 pcs with passive level envelope and 49300 pcs with a combination of renovations.

Table 92. Number and floor area of buildings with different renovations in 2030, alternative scenario.

	pcs	million m^2
Total number of buildings in 2030	181000	26.7
No energy renovations	98900	14.6
Passive-level envelope renovation	41050	6.1
A combination of renovations	41050	6.1

Results for saving potential of renovations

The following table shows saving potential for different calculation scenarios. If the renovations would be made according to baseline scenario, the savings would equal to 0.4 TWh by 2030, in terms of total energy. For alternative scenario, the savings would be 1.3 TWh.

When these are compared to the total energy consumption in Finland (279 TWh), it shows that the saving potential of baseline scenario equals to 0.1% of energy consumption in 2007, and saving potential of alternative scenario equals to 0.5% of energy country-scale energy-consumption.

Table 93. Saving potential of renovation scenarios, no renovations compared with baseline, and alternative scenarios, annual energy consumption of all the buildings of this building type in 2030.

	Heating energy			Electricity			Total energy		
	TWh/a, all buildings	Savings TWh/a	Savings %	GWh/a, all buildings	Savings TWh/a	Savings %	GWh/a, all buildings	Savings TWh/a	Savings %
Buildings, as in 2010	5.133	0	-	1.091	0	-	6.224	0	-
Renovations as in baseline scenario	4.737	0.396	8%	1.096	-0.005	0%	5.833	0.391	6%
Renovations as in alternative scenario	4.005	1.128	22%	1.104	-0.013	-1%	5.109	1.115	18%

12.3 Estimated savings in energy consumption and CO2-equ emissions, due to refurbishment of residential blocks of flats built between 1960 and 1969

Residential blocks of flats of 1960–1969 are on average five-storey buildings with a floor area of 1830 m^2 and a volume of 5990 m^3. These buildings have on average 26 apartments and they house 37 inhabitants. Their total number in Finnish residential housing stock equals to 8800 buildings, in 2010. The surface areas for this type of building are, for external walls 1080 m^2, roof 365 m^2 and base floor 330 m^2, and for windows 214 m^2. The total floor area of this building type equals to 16 million square meters.

The annual heating energy consumption for this building type is 320100 kWh/a, the annual electricity use 58000 kWh/a, and CO2-equ emissions 88 tonnes per building.

The energy consumption (heating energy and electricity) of residential blocks of flats built between 1960–1969 account for about 3.3 TWh, in 2010. This equals to 6% of the total energy consumption of the Finnish residential housing stock in 2010. The CO_2-equ emissions of this building type are 0.8 Mt, equalling to 5% of the emissions of the Finnish residential housing stock in 2010.

On country-scale, these buildings are accountable for 1% of total energy consumption in Finland (279 TWh), and for 1% of total CO_2-equ emissions (66 Mt).

Amount of buildings to be renovated between 2013 and 2030

The size of the building stock develops over time, as discussed earlier in this research. This calculation takes into account the reduction in the number of building.gs by assuming that the number of the buildings will fall from 8800 pcs of 2010 to 7700 pcs by 2030. The total floor area of this building type is estimated to be 14.2 million square meters in 2030.

As presented earlier in this research, the estimated renovation need of this building type is 3700 pcs from 2010 until 2030. Since the period of this study is 2013–2030, the renovation figure needs to be adjusted. This is done by deducting renovations done between 2010 and 2012, from the original renovation estimate. This results in that an estimated number of 3200 buildings need to be renovated between 2013–2030, equalling to 5.8 million square meters.

This means that about 41% of the buildings of this building type, which exist in 2030, will need thorough renovations between 2013 and 2030. The following table presents the energy consumption of this building type, as in 2010 without renovation, and, after selected renovation activities.

Table 94. Energy consumption of a single building, before and after different renovations, residential blocks of flats, 1960–1969.

	Heating energy consumption		Electricity consumption	
Residential blocks of flats, 1960–1969	MWh/a/ building	MWh/a/m^2	MWh/a/ building	MWh/a/m^2
Building, as in 2010	320.1	0.175	57.9	0.032
Renovated with 100mm thermal insulation	277.7	0.152	57.9	0.032
Renovated with 100mm thermal insulation and ventilation renovation	184.3	0.101	61.9	0.034
Renovated with passive-level envelope	246.3	0.135	57.9	0.032
Renovated with ventilation renovation	223.4	0.122	61.9	0.034
Renovated with a combination of renovations	123.5	0.068	62.3	0.034

Renovation scenarios

This study analyses the effects of renovations by scenario analyses. The baseline scenario, which is made to match expected renovation trends, is compared to an alternative scenario with more advanced renovation methods.

The baseline scenario assumes that by 2015, new building and energy regulations will come in place, making energy renovations mandatory when thorough renovations take place. The baseline scenario assumes that no energy renovations take place between 2013 and 2015. From 2015 onwards, 75% of all buildings in need of thorough renovations shall be renovated with 100mm thick additional thermal insulation, and 25% of them with 100mm thermal insulation and a ventilation renovation.

In other words, baseline scenario assumes that by 2030, a total number of 7700 buildings exist, from which 5000 pcs are without energy renovations, 2000 pcs with 100mm additional thermal insulation, and 700 pcs with 100mm additional thermal insulation and ventilation renovation.

Table 95. Number and floor area of buildings with different renovations in 2030, baseline scenario.

	pcs	million m^2
Total number of buildings in 2030	7700	14.1
No energy renovations	5000	9.1
100mm additional thermal insulation	2000	3.7
100mm additional thermal insulation and ventilation renovation	700	1.3

The alternative scenario assumes that new building and energy regulations will come in place in a faster schedule, already in 2013. Energy renovations are assumed to be mandatory when thorough renovations take place. The alternative scenario assumes that from 2013 onwards, 25% of all buildings in need of thorough renovations shall be renovated with passive level additional thermal insulation, 25% of them with ventilation renovation, and 50% of them with a combination of renovations, where envelope, window, ventilation and solar heat installation takes place.

In other words, the alternative scenario assumes that by 2030, a total number of 7700 buildings exist, from which 4500 pcs are without energy renovations, 800 pcs with passive level envelope, 800 pcs with ventilation renovation, and 1600 pcs with a combination of renovations.

Table 96. Number and floor area of buildings with different renovations in 2030, alternative scenario.

	pcs	million m^2
Total number of buildings in 2030	7700	14.1
No energy renovations	5000	9.1
Passive-level envelope renovation	675	1.2
Ventilation renovation	675	1.2
A combination of renovations	1350	2.5

Results for saving potential of renovations

The following table shows saving potential for different calculation scenarios. If the renovations would be made according to baseline scenario, the savings would equal to 0.2 TWh by 2030, in terms of total energy. For alternative scenario, the savings would be 0.4 TWh.

When these are compared to the total energy consumption in Finland (279 TWh), it shows that the saving potential of both of the scenarios equal to approximately 0.1% of energy consumption in Finland.

Table 97. Saving potential of renovation scenarios, no renovations compared with baseline, and alternative scenarios, annual energy consumption of all the buildings of this building type in 2030.

	Heating energy			Electricity			Total energy		
	TWh/a, all buildings	Savings TWh/a	Savings %	GWh/a, all buildings	Savings TWh/a	Savings %	GWh/a, all buildings	Savings TWh/a	Savings %
Buildings, as in 2010	2.465	0	-	0.446	0	-	2.911	0	-
Renovations as in baseline scenario	2.285	0.180	7%	0.449	-3	-1%	2.734	0.177	6%
Renovations as in alternative scenario	2.084	0.381	15%	0.454	-9	-2%	25.39	0.372	13%

12.4 Estimated savings in energy consumption and CO2-equ emissions, due to refurbishment of detached houses built between 1970 and 1979

Residential blocks of flats of 1970–1979 are on average five-storey buildings with a floor area of 1860 m^2 and a volume of 6370 m^3. These buildings have on average 26 apartments and they house 37 inhabitants. Their total number in Finnish residential housing stock equals to 12800 buildings in 2010. The surface areas for this type of building are, for external walls 1150 m^2, roof 370 m^2 and base floor 330 m^2, and for windows 215 m^2. The total floor area of this building type equals to 23.8 million square meters.

The annual heating energy consumption for this building type is 310000 kWh/a, the annual electricity use 58000 kWh/a, and CO_2-equ emissions 72 tonnes per building.

The energy consumption (heating energy and electricity) of residential blocks of flats built between 1970–1979 accounts for about 4.7 TWh, in 2010. This equals to 8% of the total energy consumption of the Finnish residential housing stock in 2010. The CO2-equ emissions of this building type are 1.1 Mt, equalling to 8% of the emissions of the Finnish residential housing stock in 2010.

On country-scale, these buildings are accountable for 2% of total energy consumption in Finland (279 TWh), and for 1% of total CO_2-equ emissions (66 Mt).

Amount of buildings to be renovated between 2013 and 2030

The size of the building stock develops over time, as discussed earlier in this research. This calculation takes into account the reduction in the number of buildings by assuming that the number of the buildings will fall from 12800 pcs of 2010 to 11600 pcs by 2030. The total floor area of this building type is estimated to be 21.6 million square meters in 2030.

As presented earlier in this research, the estimated renovation need of this building type is 6600 pcs from 2010 until 2030. Since the period of this study is 2013–2030, the renovation figure needs to be adjusted. This is done by deducting renovations done between 2010 and 2012, from the original renovation estimate. This results in that an estimated number of 5700 buildings need to be renovated between 2013–2030, equalling to 10.5 million square meters.

This means that about 49% of the buildings of this building type, which exist in 2030, will need thorough renovations between 2013 and 2030.

The following table presents the energy consumption of this building type, as in 2010 without renovation, and, after selected renovation activities.

Table 98. Energy consumption of a single building, before and after different renovations, residential blocks of flats, 1970–1979.

	Heating energy consumption		Electricity consumption	
Residential blocks of flats, 1970–1979	MWh/a/ building	MWh/a/m^2	MWh/a/ building	MWh/a/m^2
Building, as in 2010	309.5	0.167	58.3	0.031
Renovated with 100mm thermal insulation	278.2	0.150	58.3	0.031
Renovated with 100mm thermal insulation and ventilation renovation	180.4	0.097	62.4	0.034
Renovated with passive-level envelope	251	0.135	58.3	0.031
Renovated with ventilation renovation	208.6	0.112	62.4	0.034
Renovated with a combination of renovations	130.7	0.070	62.9	0.034

Renovation scenarios

This study analyses the effects of renovations by scenario analyses. The baseline scenario, which is made to match expected renovation trends, is compared to an alternative scenario with more advanced renovation methods.

The baseline scenario assumes that by 2015, new building and energy regulations will come in place, making energy renovations mandatory when thorough renovations take place. The baseline scenario assumes that no energy renovations take place between 2013 and 2015. From 2015 onwards, 75% of all buildings in need of thorough renovations shall be renovated with 100mm thick additional thermal insulation, and 25% of them with 100mm thermal insulation and a ventilation renovation.

In other words, baseline scenario assumes that by 2030, a total number of 11600 buildings exist, from which 6850 pcs are without energy renovations, 3550 pcs with 100mm additional thermal insulation, and 1200 pcs with 100mm additional thermal insulation and ventilation renovation.

Table 99. Number and floor area of buildings with different renovations in 2030, baseline scenario.

	pcs	million m^2
Total number of buildings in 2030	11600	21.6
No energy renovations	6850	12.7
100mm additional thermal insulation	3550	6.6
100mm additional thermal insulation and ventilation renovation	1200	2.2

The alternative scenario assumes that new building and energy regulations will come in place in a faster schedule, already in 2013. Energy renovations are assumed to be mandatory when thorough renovations take place. The alternative scenario assumes that from 2013 onwards, 25% of all buildings in need of thorough renovations shall be renovated with passive level additional thermal insulation, 25% of them with ventilation renovation, and 50% of them with a combination of renovations, where envelope, window, ventilation and solar heat installation takes place.

In other words, the alternative scenario assumes that by 2030, a total number of 11600 buildings exist, from which 5900 pcs are without energy renovations, 1400 pcs with passive level envelope, 1400 pcs with ventilation renovation, and 2900 pcs with a combination of renovations.

Table 100. Number and floor area of buildings with different renovations in 2030, alternative scenario.

	pcs	million m^2
Total number of buildings in 2030	11600	21.6
No energy renovations	6850	12.7
Passive-level envelope renovation	1188	2.2
Ventilation renovation	1188	2.2
A combination of renovations	2375	4.4

Results for saving potential of renovations

The following table shows saving potential for different calculation scenarios. If the renovations would be made according to baseline scenario, the savings would equal to 0.3 TWh by 2030, in terms of total energy. For alternative scenario, the savings would be 0.7 TWh.

When these are compared to the total energy consumption in Finland (279 TWh), it shows that the saving potential of baseline scenario equals to 0.1% of energy consumption in Finland, and saving potential of alternative scenario equals to 0.3% of energy country-scale energy-consumption.

101. Saving potential of renovation scenarios, no renovations compared with baseline, and alternative scenarios, annual energy consumption of all the buildings of this building type in 2030

	Heating energy			Electricity			Total energy		
	TWh/a, all buildings	Savings TWh/a	Savings %	TWh/a, all buildings	Savings TWh/a	Savings %	TWh/a, all buildings	Savings TWh/a	Savings %
Buildings, as in 2010	3.590	0	-	0.676	0	-	4.266	0	-
Renovations as in baseline scenario	3.322	0.268	7%	0.681	-0.004	-1%	4.003	0.264	6%
Renovations as in alternative scenario	2.976	0.614	17%	0.692	-0.016	-2%	3.668	0.598	14%

12.5 Investment and life cycle costs of selected house types

This section analyses the economy of selected renovation concepts in the cases of most typical residential house types in Finland.

The total costs caused by the selected concepts of improvement of energy efficiency have been collected to Table 96. The calculations are based on the following renovation concepts:

- Required energy savings connected to necessary renovation: additional thermal insulation (100 mm) in connection of refurbishment of facades, improvement of air-tightness, adjustment of heating system. Improvement of ventilation in the connection of pipeline operations possible in some cases but included only in calculation concerning whole residential building stock.
- Building with passive level envelop in detached houses
- Building with new ventilation and passive level envelop in connection of pipeline operations in residential blocks of flats
- Almost net zero energy building with passive level envelope, mechanical ventilation with effective heat recovery and solar collectors for water heating.

Table 102. Total energy renovation costs of Mecoren concepts. Unit costs presented at a later table in this chapter.

	Required energy savings	Building with passive level envelope	Almost net zero energy building
	€/ m^2	€/ m^2	€/ m^2
Energy renovation cost in detached houses 1940–1959	+200	+400	+600
Energy renovation cost in detached houses 1980–1989	+75	+200	+350
Energy renovation cost in residential bocks of flats 1960–1969	+70	+175	+250
Energy renovation cost in residential bocks of flats 1970–1979	+50	+165	+225

Resale value has been estimated to be 50% of extra costs caused by extra insulation of building façade meaning

- necessary renovation: 25% of investment cost focusing to building envelope
- passive level renovation: 25% of investment cost focusing to building envelope.

The energy costs have been calculative in average in 20 years with +4%/y real rise of energy prices.

- heating energy in blocks of flat: 103 €/kWh
- heating energy in detached houses: 150 €/kWh
- electricity energy in all buildings: 150 €/kWh.

The results of economical calculations are presented in Tables 103–106. The following recommendations are based on the results:

- All alternative energy saving methods are favourable in the case of detached houses 1940–1959 as the effect of improving insulation of envelope is very high. Also almost net zero energy level may be achieved in an economical way when connected to an extensive renovation and when there is a need to improve quality of indoor climate. Then the façade appearance must not be deteriorated.
- In the case of relatively new detached houses 1980–1989 almost net zero energy target is the most economical in the situation with a need for extensive renovation and need to improve quality of indoor climate.
- In the case of detached houses the target of almost net zero energy building is recommended while in the case of residential blocks of flats passive level envelope and possible renewal of ventilations are the most economi-

cal in situation when there is a need for extensive renovation and need to improve the quality of indoor climate.

Table 103. Energy demands and costing of possible energy savings in detached houses, 1940–1959 within calculation period of 20 years.

Detached house 1940–1959 107 room-m^2	Unit	Basis	Required Energy savings	Building with passive level envelope	Almost net zero energy building
Heating energy	MWh/y	29.8	20.4	11.6	5.0
Electricity energy	kWh/y	5.4	5.4	5.4	6.0
ECONOMICAL EFFECTS					
Difference in investment cost	€		21 400	42 900	64 200
Investment supports	€		-2 100	-4 300	-6 400
Residual value (envelope)	€		-5 300	-10 600	-10 600
Difference in financial cost	€/20y		5 400	10 700	16 100
Difference in heating cost	€/20y		-28 200	-54 600	-74 400
Difference in electricity cost	€/20y		0	0	+1 800
Difference in Life Cycle Cost	€/20y		-8 800	-15 900	-14 800
Difference in Life Cycle Cost	€/y		-440	-795	-740
Difference in Life Cycle Cost	€/m^2/y		-4.1	4.5	6.2

Table 104. Energy demands and costing of possible energy savings in detached houses, 1980–1989 within calculation period of 20 years.

Detached house 1980–1989 148 room-m^2	Unit	Basis	Required energy savings	Building with passive level envelope	Almost net zero energy building
Heating energy	MWh/y	28.4	25.4	19.6	6.0
Electricity energy	kWh/y	5.4	5.4	5.4	6.0
ECONOMICAL EFFECTS					
Difference in investment cost	€		11 100	29 600	52 000
Investment supports	€		-1 100	-3 000	-5 200
Residual value (envelope)	€		-2 800	-7 400	-7 400
Difference in financial cost	€/20y		2 800	7 400	13 000
Difference in heating cost	€/20y		-9 000	-26 400	-67 200
Difference in electricity cost	€/20y		0	0	+1 800
Difference in Life Cycle Cost	€/20y		1 000	200	-13 000
Difference in Life Cycle Cost	€/y		50	10	-650
Difference in Life Cycle Cost	€/m2/y		0.3	0.1	-4.4

Table 105. Energy demands and costing of possible energy savings in residential blocks of flats 1960–1969 within calculation period of 20 years.

Residential block of flats 1960–1969 1 830 room-m²	Unit	Basis	Required energy savings	Building with new ventilation and passive level envelope	Almost net zero energy building
Heating energy	MWh/y	320.1	277.7	152.9	80.0
Electricity energy	kWh/y	57.9	57.9	57.9	62.3
ECONOMICAL EFFECTS					
Difference in investment cost	€		128 000	293 000	458 000
Investment supports	€		-13 000	-29 000	-46 000
Residual value (envelope)	€		-32 000	-57 000	-57 000
Difference in financial cost	€/20y		32 000	57 000	114 000
Difference in heating cost	€/20y		-87 000	-344 000	-494 000
Difference in electricity cost	€/20y		0	0	+13 000
Difference in Life Cycle Cost	€/20y		28 000	-80 000	-12 000
Difference in Life Cycle Cost	€/y		1 400	-4 000	-600
Difference in Life Cycle Cost	€/m²/y		0.8	-2.2	-0.3

Table 106. Energy demands and costing of possible energy savings in Residential block of flats 1970–1979 within calculation period of 20 years

Residential block of flats 1970–1979 1 860 room-m²	Unit	Basis	Required energy savings	Building with new ventilation and passive level envelope	Almost net zero energy building
Heating energy	MWh/y	309.5	278.5	153.2	75.0
Electricity energy	kWh/y	58.3	58.3	58.3	62.9
ECONOMICAL EFFECTS					
Difference in investment cost	€		140 000	307 000	419 000
Investment supports	€		-14 000	-31 000	-42 000
Residual value (envelope)	€		-35 000	-47 000	-47 000
Difference in financial cost	€/20y		35 000	47 000	105 000
Difference in heating cost	€/20y		-64 000	-322 000	-483 000
Difference in electricity cost	€/20y		0	0	+13 000
Difference in Life Cycle Cost	€/20y		62 000	-46 000	-35 000
Difference in Life Cycle Cost	€/y		3 100	-2 300	-1 750
Difference in Life Cycle Cost	€/m²/y		1.6	-1.2	-0.9

Investment and life cycle costs of renovation concepts in whole residential building stock

The main results of calculations presented previously have been gathered to the following two tables to show the total effects of selected renovation concepts on the costing and concepts of whole residential building stock. The purpose is to identify the importance of alternative approaches and not to show detailed calculations. The calculation has been restricted to heating energy because the calculative changes in electricity energy are very small and easily mixed in user-electricity.

Calculation in the case of whole residential building stock are based on the following:

- Required energy savings connected to necessary renovation: additional thermal insulation (100 mm) in connection to refurbishment of facades, improvement of air-tightness, adjustment of heating system. Requirement to renew ventilation in the connection of pipeline operations included in 25% of renovations.
- Building with new ventilation and passive level envelop in connection to pipeline operations in 25% of renovations in whole residential building stock.
- Almost net zero energy building passive level envelope, mechanical ventilation with effective heat recovery and solar collectors for water heating, heat pump system, pellet system etc.

As the renovated area of the residential building stock in Finland is annually about 7 million m^2 the corresponding extra investment cost caused by required energy saving actions is 650 million/y. However, the assessed investment cost because of recommended energy saving renovations (see the above list) is 2 050 million/y. These costs also take into account the more expensive costs in protected houses. The annual savings in heating costs because of recommended concepts would be about 60 million €/y lower than in case of required actions.

The share of extra labour by recommended concepts would be about 17 000 person years per year higher than in case of demanded actions. The annual needs for public supports are supposed to be at least 65 million €/y in the case of required energy savings and almost 200 million €/y in the case of recommended concepts.

Table 107. Total volumes, energy demand, costs and labour effects of renovation concepts in the whole residential building stock in Finland.

Whole residential building stock Total area 266 000 mill. m^2 (2010), renovated area 140 000 m^2 by 2030.	Renovated area in year mill. **m^2/y**	Corresponding annual heating cost savings in average **mill. €/y**	Extra investment costs caused by savings 2030 **mill. €/y**	Annual need for public support (10…15% of investment) **mill. €/y**	Labour effects **Person years/y**
Renovated totally with required energy savings	7.0	-45	+650	65…100	9 000
Renovated totally by new ventilation and passive level envelope	7.0	-70	+1 350	150…200	17 000
Renovated totally to almost net zero energy buildings	7.0	-140	+2 750	270…400	31 000
Renovated 50% by new ventilation and passive level envelope and 50% to almost net zero energy buildings	7.0	-105	+2 050	150…200	26 000

The following table shows the effects of reduction of residential buildings stock and effects of both demanded actions and recommended renovation concepts by 2030. The total heating energy consumption of present building stock will be 29% lower in year 2030 than in year 2010 meaning 18% lower energy demand when taking the reduction of building stock in account. Then by means of recommended renovation concepts the heating energy demand is 45% lower in year 2030 than in year 2010 when taking also the reduction of building stock in account. The changes in CO2 emissions are near to changes in heating energy demands. This means big challenges and changes for energy supply.

Table 108. Total heating energy demand of whole residential building stock 2010 by means of demanded actions or recommended concepts taking also the reduction of building stock in account.

	Heating energy consumptions TWh/y; Required renovation actions	Heating energy consumption TWh/y; Recommended renovation concepts	Savings in energy demand in present residential building stock 2030
Residential building stock 2010	51	51	
Reduction by building stock 2010 → 2030	- 7	-7	0%
Renovated totally with required energy saving actions 2013–2030	- 6		-14%
Renovated 50% by new ventilation and and passive level envelope and 50% to almost net zero energy buildings		-20	-45%
Residential building stock 2030	36	24	

Only the recommended concepts make it possible to achieve the national ERA – targets shown in the following figure.

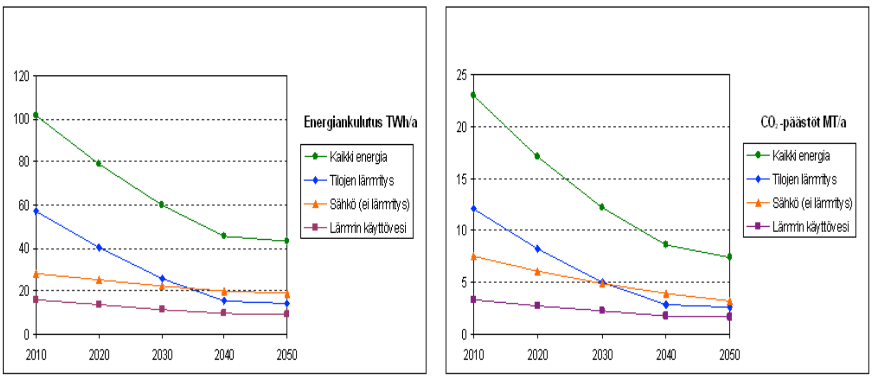


Figure 84. Targets to development of energy consumption and CO2 emissions in whole building stock (all types of buildings) in Finland [ERA 17].

This means

- energy-intensive facility survey methods
- development and supply of flexible renovation concepts by companies
- clear decision making and procurement abilities of facility owners consulted by able consults.

13. Summary

Background and objectives

The IPCC synthesis report lists buildings as having the largest estimated economic mitigation potential among the sector solutions investigated. IPCC suggests the following three main categories for buildings:

- reducing energy consumption and embodied energy in buildings
- switching to low-carbon fuels including a higher share of renewable energy
- controlling the emissions of non- CO_2 GHG gases

The European Union targets for sustainable growth include:

- reducing GHGs by 20% (30%) compared to 1990 levels by 2020
- increasing the share of renewables in final energy consumption to 20%
- moving towards a 20% increase in energy efficiency.

According to the roadmap for moving to a competitive low-carbon economy in 2050, the long-term target is to reduce GHGs by 80 (to 95%) by 2050 meaning the reduction target of 40% by 2030 and 60% by 2040. The built environment provides low-cost and short-term opportunities to reduce emissions especially through the improvement of the energy performance of buildings. GHGs in this area could be reduced by around 90% by 2050.

This report analyses the impacts of alternative renovation scenarios on Finnish building stock in terms of energy use and greenhouse gases (GHGs). In addition to the assessment of the renovation concepts on building stock, the report also

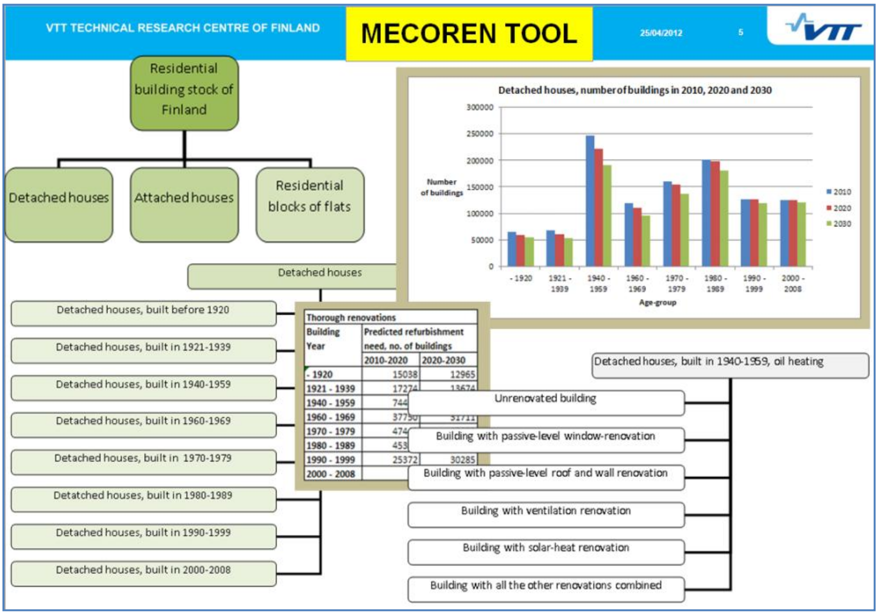
- discusses and gives recommendations about the use of environmental data for energy sources
- discusses and makes conclusions about the significance of building materials in renovation projects from the view point of greenhouse gases and total energy use
- discusses and makes recommendations about different renovations concepts assess and makes conclusions about the economic impacts of building renovation.

The starting point for the assessment was the information about the current building stock. The total floor area of different building groups in Finland is roughly 270 Mm^2 of which the floor area of detached houses from 1940–2009 and residential blocks of flats from 1960–1989 form a big share:

Construction year	Detached houses(floor area, m2)	Attached houses (Floor area, m2)	Residential blocks of flats (floor area, m2)	Total
->1920	7 861 093	298 131	2 419 008	10 578 232
1921 - 1939	7 311 690	172 284	4 874 608	12 358 582
1940 - 1959	25 707 065	494 981	9 016 469	35 218 515
1960 - 1969	14 081 347	1 913 140	15 864 934	31 859 421
1970 - 1979	22 011 443	7 647 045	23 541 282	53 199 770
1980 - 1989	29 158 961	11 484 936	12 043 634	52 687 531
1990 - 1999	18 973 584	5 734 341	10 832 394	35 540 319
2000 - 2008	20 077 600	4 078 161	9 308 603	33 464 364
Unknown year	2 965 023	309 566	691 041	3 965 630
Sum	148 147 806	32 132 585	88 591 973	268 872 364

Assessment results

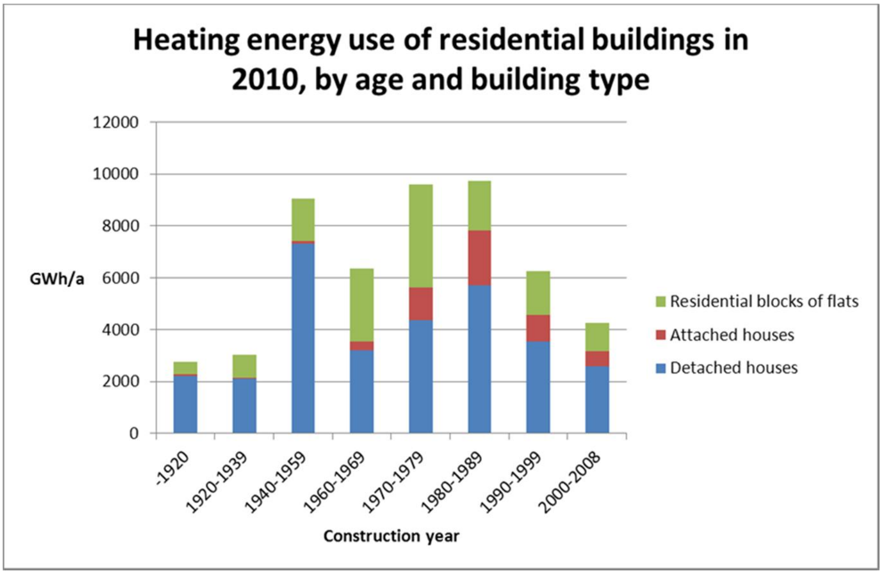
The MECOREN tool was developed in order help the assessment of the effect of alternative renovation methods on final energy use and GHGs:



According to Motiva, the total final energy consumption in Finland in 2010 was 279 TWh. The share of all buildings' energy use was 70 TWh + 24 TWh (electricity). The OECD data of Finnish GHG emissions show that the annual emissions in Finland in 2009 were 66 million tonnes (Mt).

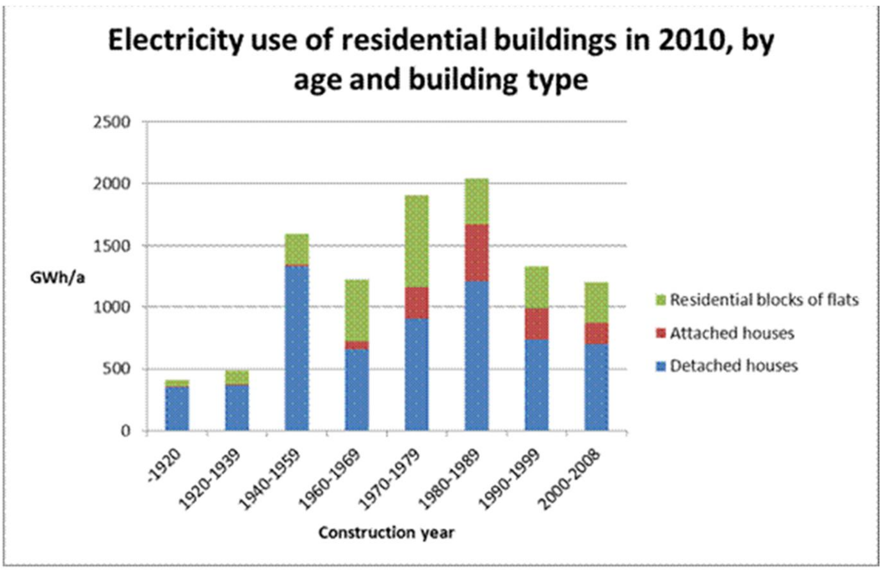
The calculated total annual heating energy use in 2010 is 50.6 TWh of which

- detached houses use 31 TWh (61%)
- attached houses use 5.5 TWh (11%) and
- residential blocks of flats 14.5 TWh (28%).



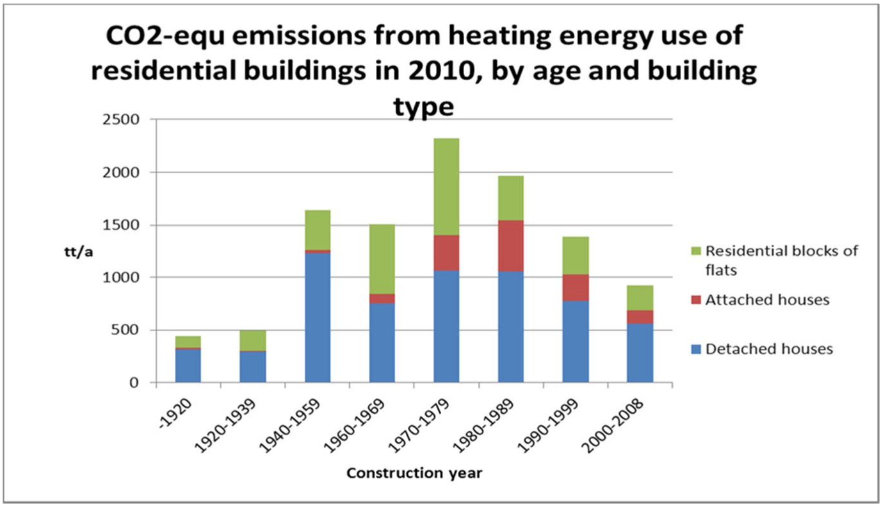
The calculated total annual electricity use is 10.2 TWh, from which

- detached houses use 6.3 TWh,
- attached houses use 1.2 TWh and
- residential blocks of flats use 2.7 TWh.



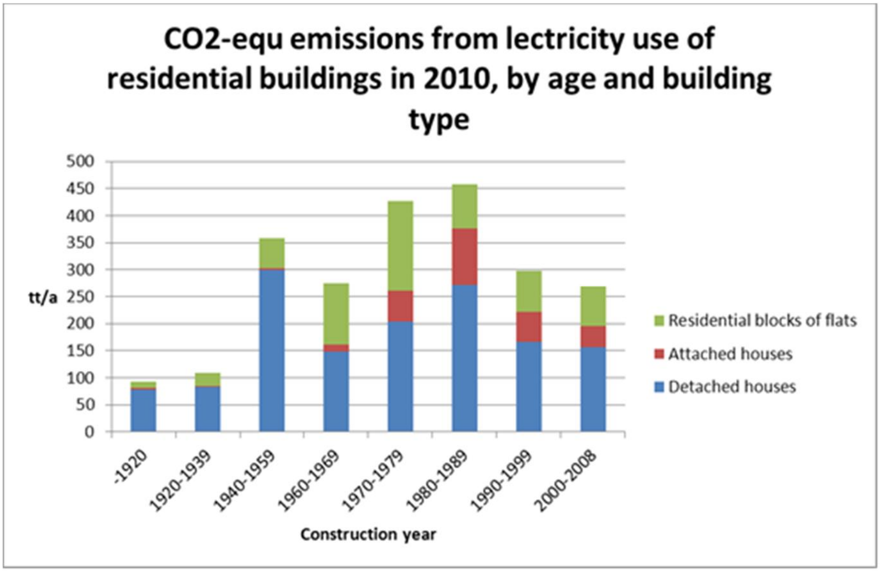
The assessed total annual CO2-emissions from the heating energy use of the residential housing stock is 10.7 Mt of which the share of

– detached houses is 6.05 Mt (57%)
– attached houses 1.35 Mt (12%)
– residential blocks of flats 3.3 Mt (31%).



The annual CO2-equ emissions from residential buildings' electricity use are 2.3 Mt of which the share of

– detached houses is 1.4 Mt
– attached houses is 0.3 Mt
– residential blocks of flats is 0.6 Mt.



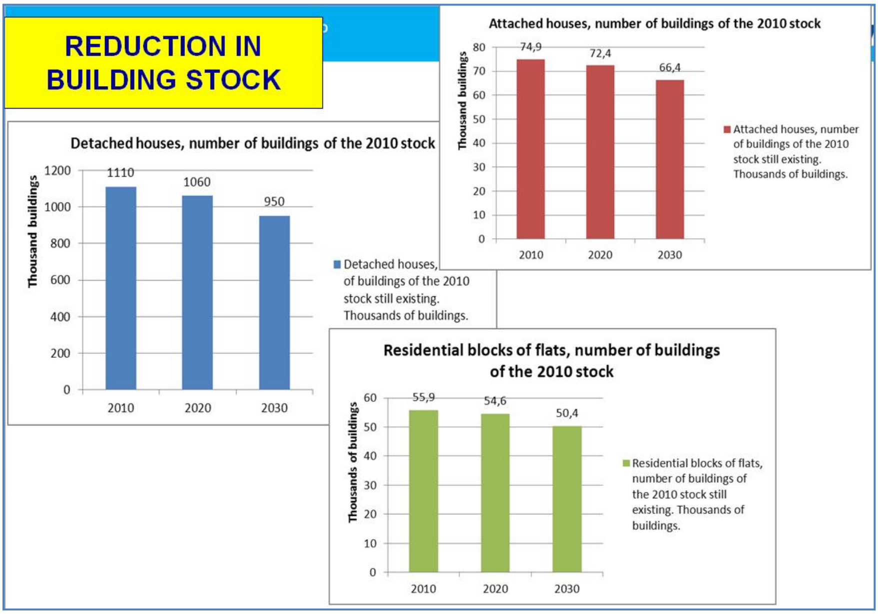
If the country-level energy use is to be reduced significantly, for example, by 5%...10%, by reducing heating energy need of residential buildings only, the heating energy use would need to be reduced greatly. If the heating energy demand of residential buildings could be cut by 30%, this would result in (15 TWh) 5% savings on country-level energy use, and if it could be cut by 60%, the savings would equal to (31 TWh) 10%. This means that all options for improved energy performance and reduced GHGs have to be found out and effective measures of steering should be implemented on all levels.

It was also assessed that the outgoing buildings of the stock decrease the annual total energy consumption by

– 6.8 TWh by 2030.

The outgoing share of building stock corresponds to GHG reduction of

– 1.7 Mt by 2030.



The impact of different renovation methods was assessed as follows:

- passive level outer walls and roof
  - U-value 0.085 W/m^{2}K for outer walls and 0.075 W/m^{2}K for roof.
- passive level windows and improved air-tightness of the building envelope
  - U = 0.7 W/m^{2}K
  - 4.0 -> 3.0 for detached and attached houses, 2.5 -> 2.0 for blocks of flats
- renovation of ventilation system to mechanical supply and exhaust system
  - A-class fans and 75% yearly heat recovery efficiency
- utilization of solar heat for heating of service water
  - 50% of the annual service water heating demand
- a combination of the four renovations.

The assessment took into account the assessed outgoing share of the current stock and the share of buildings needing either light or thorough renovation during the coming years.

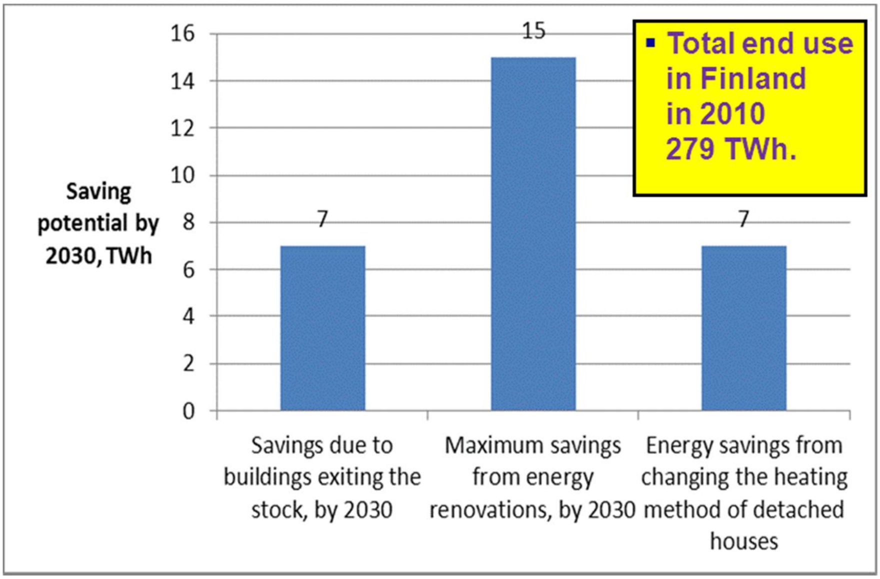
NEED OF RENOVATION	Predicted renovation need, number of buildings that need thorough renovations		
Building year	Detached houses	Attached houses	Residential blocks of flats
- 1920	28000	310	730
1921 - 1939	30950	200	1190
1940 - 1959	127840	410	2850
1960 - 1969	69460	1300	3720
1970 - 1979	93420	5870	6620
1980 - 1989	115010	11890	5210
1990 - 1999	55660	8090	2760
2000 - 2008	25030	1930	520
	545400	30000	23600

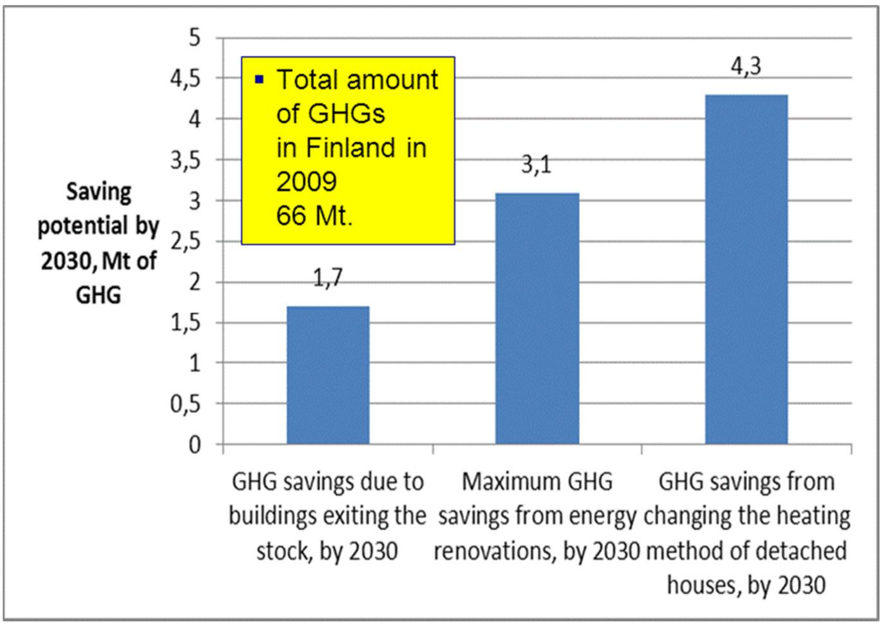
	Predicted renovation need, number of buildings that need light renovation		
Building year	Detached houses	Attached houses	Residential blocks of flats
- 1920	34500	380	1040
1921 - 1939	33880	250	1690
1940 - 1959	105910	580	3900
1960 - 1969	45190	1840	4950
1970 - 1979	64090	8310	6090
1980 - 1989	84500	16840	3900
1990 - 1999	70870	7700	5400
2000 - 2008	50050	3870	2330
	489000	39770	29300

It was assumed that passive level windows would be changed to all buildings that need light renovation during the coming years. It was also assessed that either passive level envelop renovation, ventilation renovation or solar heat installation or a combination of these would be done for all building that need thorough renovation during coming years. The assessed final energy use and related GHG emissions would then be as follows:

	Energy Heating TWh	Energy Electricity TWh	Energy Total TWh	GHG emissions Total Mt
2030, no energy renovations	44	8.9	53	11
Passive-level envelope	35	8.9	44	9.4
Ventilation renovation	41	9.2	50	11
Solar heat installation	43	8.9	52	11
Window renovation	42	8.9	51	11
Renovation combination	29	9.2	38	8.2

Changes in the heating method were studied for two different cases. The energy consumption of detached houses, if left without energy renovations, would equal to 32 TWh in 2030, resulting in GHG emissions of 6.4Mt. The calculation results show that if all the detached houses with electrical heating were converted to ground heating, the total energy consumption of detached houses would fall to 23 TWh, resulting in GHG emissions of 4.6 Mt. The corresponding savings, compared to baseline case, would equal to 8.6 TWh, and 1.8 Mt of GHGs. If all the detached houses with oil heating would be converted to wood heating, the total energy need would rise (due to inefficiencies in wood heating systems) to 33 TWh. However, the GHG emissions would drop to 3.8 Mt, due to the more favourable environmental profile of wood-heating. The increase in energy consumption, compared to baseline case equals to 1.5 TWh, and savings in GHG emissions to 2.6 Mt.





Consideration of the environmental impact of energy

When doing assessments about the GHGs of buildings it is important to choose a right method with help of which the emissions of energy are calculated. There are several issues that should be considered.

When an electricity power plant produces multi-products such as power, heat, steam, cooling or refinery products, the problem of emission allocation is encountered. The impact of the method of allocation is especially important in Finland because of the high rate of combined heat and power (CHP) production. This report uses two types of methods to allocate the inputs and outputs for electricity and heat in combined production – these are the so-called benefit distribution method and energy method. When interpreting the results of any assessment, consideration should be given to the used method because its significant effect of the final results especially in countries where CHP production is much utilized.

The following GHG emission values of electricity and district heat – based on average results of years 2004–2008 – are recommended for use:

	Benefit		Energy	
	Electricity	District heat	Electricity	District heat
CO2 fossil, kg/MWh	309	236	222	273
CO2 biogenic, kg/MWh	121	134	67.5	160
CH4, kg/MWh	0.821	0,364	0.709	0,424
N2O, kg/MWh	0.000654	0.000397	0.000523	0.000448
GHG, kg/MWh	330	245	240	283

The consideration of seasonal changes and marginal impacts on the production of heat and power is also very important. The consideration of the seasonal changes is important especially when assessing the effects of such energy-saving renovation concepts that do not cause a constant reduction in the demand for delivered energy but bring about savings that vary along seasons. When assessing the environmental impacts of the savings, the use of the monthly average values of heat and electricity instead of annual average values, should be considered. Or even more, the impacts of seasonal savings during winter time could be assessed with help of marginal values.

The current demand for electricity is bigger than supply which is thus increased with help of import. This takes place mainly from Russia and is mainly based on the use of fossil fuels. Part of the heat and power generation takes place in separate plants. Changes in demand up to a certain amount could primarily be responded with help of changes in fossil fuel based power generation also in the cases where the reduction takes place in warm seasons. When the potential change in power generation methods because of reduced / increased demand is known, this should be taken into account. The use of as realistic impact models as possible is recommended, when assessing the potential of significant changes.

One of the assessment results shows that, if all the existing detached houses with electrical heating were converted to ground heating by 2030, the total demand for delivered electricity and total release of GHGs of detached houses would decrease by 8.6 TWh and 1.8 Mt GHG. However, assuming that half of 8.6 TWh is produced in condensing power plants in winter, the saving becomes 4.5 Mt GHGs, if we use marginal values for the GHGs of electricity (meaning an emission value of roughly CO2e = 1000 g/kWh instead of roughly CO2e = 300 g/kWh).

On the other hand, the long-term impact of building renovation goes sometimes against the use of marginal impacts. The impacts are typically assessed with using a time period of 20–50 years and it is also important to take into account the predicted changes in the production of power and heat. According to the base case scenario, the predicted emissions for district heat and electricity (calculated with using the energy allocation method) are as follows:

- GHGs (g/kWh) of electricity 230 (2010), 179 (2020) and 36 (2030)
- GHG /g/kWh) district heat 243 (2010), 216 (2020 and 191 (2030).

As there is a rapid change in the assessed values between the years 2010, 2020 and 2030, the consideration of this in LCAs of buildings has a significant effect on final results. It is recommended that especially when making building specific LCAs over several decades' period, the assessed change in emission values should be considered. An example of the significance of the issue was shown with help of assessment: According to the basic assessment results the total final energy demand of existing buildings in 2030 is 29 TWh for heating spaces and 9.2 TWh because of electricity use. Assuming that the energy is produced with help of district heat and electricity and by using either 2010 values or 2030 predicted values for GHGs, we receive different results for the assessed impact of building stock in 2030. The corresponding assessed GHGs of the existing building stock are 9.1 Mt by using the present values but the assessed GHG of the existing building stock in 2030 is 4.7 by using the predicted values (2030).

Consideration of this issue is also important when assessing the shares of materials (produced now or in a very near future) to the impact of operational energy use. The significance can be indicated with help of a calculation example of the report: Among the calculations a multi-storey building was assessed. When the GHGs because of total operational energy use during 50 was calculated by using the emission values of 2010, the result was 1.99 Mt CO2e, but when the total GHGs were calculated considering the predicted change in the emission values of electricity and district heat, the assessed result was 1.44 Mt CO2e. Thus also the share of building materials' share from the total GHGs increases (in this example it increases from below 20% to roughly 25%). The share of materials in the latter case roughly equals to the combined share of heating and electricity use while the heating of water is responsible for roughly 50% of the GHGs.

When making building stock based analyses about the significance of renovation scenarios, it is also important to take into account, whether a particular decrease in the demand for delivered electricity is actually needed as a partial measure in order to make the change (decrease of GHGs) to happen. The ability of building sector to react to the challenge is indeed an important prerequisite for Finland to be able to respond to the requirements of decreasing GHGs. The role of building sector is double in such a way that it is first important to decrease the GHGs of the building stock with help of improved energy performance and thus further more to enable the better power generation (in terms of GHGs) with help of reduced demand for delivered electricity.

Renovation concepts for residential buildings

The report introduces different kinds of renovation concepts for the refurbishment of building envelop and for the improvement of building services. The report gives guidelines, presents good examples and shows typical risks and problematic issues. Guidelines and recommendations are given for:

- External thermal insulation
- Internal thermal insulation
- Replacement of the insulation material
- Additional thermal insulation of roofs
- Additional thermal insulation of the base floor
- Window replacement and improvements in air-tightness
- Increasing the air tightness of the building envelope
- Renovation of ventilation system
- Heating systems.

Economical assessment of renovation concepts

The potentials to remarkably and economically improve the energy performance of buildings are linked to the cases where an extensive renovation is needed for an outdated building. However, also separately done changes of windows, refurbishment of facades etc. should lead to a reasonable improvement of energy performance.

The life cycle impacts of successful renovation concepts can be summarized as follows.

- significant reduction of energy consumption and related GHGs
- reasonable increase of investment cost
- reasonable savings in life cycle costs
- increase of resale value.

The most significant increase in economic value (market value) by means of extensive renovation can be achieved when the building or the block of buildings is located in a relatively valuable neighbourhood and when the whole neighbourhood is renovated at the same time. In these cases the costs of renovation can be compensated with help of the increase of market value. This can also be realised by increasing the density of the area. Effects on economic values of houses and buildings and departments may sometimes be significant because of improved performance and because of aesthetical improvement.

The economic and environmental impact of the renovation of certain building types and groups was also assessed. The assessment was done for detached buildings from 1940–1959, detached buildings from 1980–1989 and for residential blocks of flats from 1960–1069 and from 1970–1979. These groups of building were selected because their big share from the whole building stock. Alternative renovations concepts were as follows: Renovated with 100mm thermal insulation, Renovated with 100mm thermal insulation and ventilation renovation, Renovated with passive level envelope, Renovated with a combination of renovations. On the basis of economical assessment results the following recommendations are given:

The following recommendations are based on the results:

- All studied alternative energy saving methods are favourable in the case of detached houses from 1940-1959 as the effect of the improved insulation of envelope is very high. Also almost net zero energy level may be achieved in an economical way when connected to an extensive renovation and when there is a need to improve the quality of indoor climate.
- In the case of relatively new detached houses (1980-1989), almost net zero energy target is the most economical when there is a need for extensive renovation and need to improve the quality of indoor climate.
- In the case of detached houses the target of almost net zero energy building is recommended while in the case of residential blocks of flats passive level envelope and possible renewal of ventilations are the most economical in situation when there is a need for extensive renovation and need to improve the quality of indoor climate.

The economic impact studies were also made regarding the whole existing building stock. In the case of required renovations it was assumed that 75% of all buildings which need thorough renovations shall be renovated with 100 mm thick additional thermal insulation and 25% of them with 100 mm thermal insulation and a ventilation renovation. The total volumes, cost savings, investment costs, needed annual support and labour effects of renovation concepts in the whole residential building stock in Finland were assessed to be as follows:

Whole residential building stock Total area 266 000 mill. m² (2010), renovated area 140 000 m² by 2030.	Renovated area in year mill. **m²/y**	Corresponding annual heating cost savings in average **mill. €/y**	Extra investment costs caused by savings 2030 **mill. €/y**	Annual need for public support (10…15% of investment) **mill. €/y**	Labour effects **Person years/y**
Renovated totally with required energy savings	7.0	-45	+650	65…100	9 000
Renovated totally by new ventilation and passive level envelope	7.0	-70	+1 350	150…200	17 000
Renovated totally to almost net zero energy buildings	7.0	-140	+2 750	270…400	31 000
Renovated 50% by new ventilation and passive level envelope and 50% to almost net zero energy buildings	7.0	-105	+2 050	150…200	26 000

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Appendix A: Calculation of electricity use of service water and heating water network

Service water network

The average heat loss of the service water ring duct as a function of the building volume V_b (m^3) is estimated to be 7 kWh/m^3. The average service water heating power P_{sw} (kW) is:

$$P_{sw} = \frac{7\ kWh/m^3 \cdot V_b}{8760\ h} \tag{1}$$

The average mass flow m (kg/s) is calculated by dividing the heating power with the average temperature difference Δt (5 K) and the specific heat capacity of water $c_{p,w}$ (4.19 kJ/kgK):

$$m = \frac{P_{sw}}{\Delta t \cdot c_{p,w}} \tag{2}$$

The annual pump electricity power (kW) is then calculated by multiplying the mass flow with the pressure difference of the network Δp (kPa) and dividing with the water density ρ (kg/m^3) and the pump efficiency η:

$$P_{sw} = \frac{m \cdot \Delta p}{\rho \cdot \eta} \tag{3}$$

The estimated service water network pressure difference was 25 kPa and the estimated pump efficiency was 15% for the detached house and 30% for the attached house and for the residential blocks of flats.

The annual service water network pump electricity use (kWh) is calculated by multiplying the pump electricity power with the operation time t (8760 hours):

$$E_{sw} = P_{sw} \cdot t \tag{4}$$

Heating water network

The pumping electricity use of the heating water network (oil heating, district heating, wood heating) is estimated from the annual room heating energy demand E_d (kWh/a). The annual room heating energy demand is the room heating energy use calculated with WinEtana multiplied with the heating system efficiency. The average heating power P (kW) is

$$P = \frac{E_d}{8760\ h} \tag{5}$$

The average heating water mass flow m (kg/s) is calculated by dividing the heating power with the average temperature difference Δt (30 K) and the specific heat capacity of water $c_{p,w}$:

$$m = \frac{P}{\Delta t \cdot c_{p,w}} \tag{6}$$

The annual heating water network pump electricity power (kW) is calculated by multiplying the mass flow with the pressure difference of the network Δp (kPa) and dividing with the water density ρ (kg/m^3) and pump efficiency η:

$$P_{hw} = \frac{m \cdot \Delta p}{\rho \cdot \eta} \tag{7}$$

The estimated heating water network pressure difference was 40 kPa and the estimated pump efficiency was 15% for the detached house and 30% for the attached house and for the block flat house.

The annual heating water network pump electricity use (kWh) is calculated by multiplying the pump electricity power with the operation time t (8760 hours):

$$E_{hw} = P_{kw} \cdot t \tag{8}$$

Appendix B: Energy calculation result tables on building level – exemplary buildings for the existing stock

This section presents calculation results for the energy consumption of different building types. The results are given for each of the building types, divided by their construction year and heating type. Also, results for renovated buildings are calculated. The renovated cases presented here are: passive-level building envelope, ventilation renovation, solar-heat installation, window-renovation and a combination of the other renovations.

a) Calculation results for unrenovated buildings

Energy consumption of unrenovated detached houses.

Energy consumption of unrenovated detached houses	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	32 874	1 291	31 583	5 450	256	82	44
–1920, electrical heating	28 430	1 291	27 139	5 400	220	71	44
–1920, wood heating	39 918	1 291	38 627	5 450	314	101	44
–1920, district heating	28 513	1 291	27 222	5 450	221	71	44
–1920, geothermal heating	9 495	430	9 065	1 815	74	24	15
1920–1939, oil-heating	29 364	1 146	28 218	5 530	258	83	51
1920–1939, electrical heating	25 680	1 146	24 534	5 360	224	72	49
1920–1939, wood heating	36 093	1 146	34 947	5 390	320	103	49
1920–1939, district heating	25 781	1 146	24 635	5 390	225	72	49
1920–1939, geothermal heating	8 585	382	8 203	1 795	75	24	16
1940–1959, oil-heating	28 755	1 122	27 633	5 530	259	83	52
1940–1959, electrical heating	24 849	1 122	23 727	5 358	223	71	50
1940–1959, wood heating	35 441	1 122	34 319	5 390	322	103	51
1940–1959, district heating	24 953	1 122	23 831	5 390	224	72	51
1940–1959, geothermal heating	8 309	374	7 936	1 795	74	24	17
1960–1969, oil-heating	26 954	1 261	25 693	5 630	213	69	47
1960–1969, electrical heating	22 457	1 261	21 196	5 430	175	57	45
1960–1969, wood heating	31 625	1 261	30 364	5 460	251	81	45
1960–1969, district heating	22 589	1 261	21 328	5 460	177	57	45
1960–1969, geothermal heating	7 522	420	7 102	1 818	59	19	15
1970–1979, oil-heating	27 676	1 493	26 183	5 750	187	59	41
1970–1979, electrical heating	23 831	1 493	22 338	5 520	160	50	39
1970–1979, wood heating	34 061	1 493	32 568	5 550	233	73	40
1970–1979, district heating	23 982	1 493	22 489	5 550	161	51	40
1970–1979, geothermal heating	7 986	497	7 489	1 848	54	17	13
1980–1989, oil-heating	30 440	1 601	28 839	6 280	195	61	43
1980–1989, electrical heating	26 290	1 601	24 689	6 030	167	52	41
1980–1989, wood heating	37 500	1 601	35 899	6 060	243	76	41
1980–1989, district heating	26 410	1 601	24 809	6 060	168	52	41
1980–1989, geothermal heating	8 795	533	8 261	2 018	56	17	14
1990–1999, oil-heating	31 090	1 682	29 408	6 370	193	59	42
1990–1999, electrical heating	26 570	1 682	24 888	5 620	163	50	37
1990–1999, wood heating	36 770	1 682	35 088	6 820	230	70	45
1990–1999, district heating	26 660	1 682	24 978	6 150	164	50	40

Energy consumption of unrenovated detached houses	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
1990–1999, geothermal heating	8 878	560	8 318	2 048	55	17	13
2000–2008, oil-heating	24 760	1 803	22 957	6 500	140	43	40
2000–2008, electrical heating	21 280	1 803	19 477	5 750	119	36	35
2000–2008, wood heating	30 140	1 803	28 337	6 500	173	53	40
2000–2008, district heating	21 220	1 803	19 417	6 280	119	36	38
2000–2008, geothermal heating	7 066	600	6 466	2 091	39	12	13

Energy consumption of unrenovated attached houses.

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	93 468	16 520	76 948	14 861	195	64	38
–1920, electrical heating	82 252	16 520	65 732	14 299	167	55	36
–1920, district heating	82 045	16 520	65 525	14 350	166	54	36
–1920, geothermal heating	27 321	5 501	21 820	4 779	55	18	12
1920–1939, oil-heating	83 734	14 669	69 065	14 592	199	65	42
1920–1939, electrical heating	74 482	14 669	59 813	14 020	172	56	40
1920–1939, district heating	73 484	14 669	58 815	14 130	169	55	41
1920–1939, geothermal heating	24 470	4 885	19 585	4 705	56	18	14
1940–1959, oil-heating	105 294	19 220	86 074	15 232	188	61	33
1940–1959, electrical heating	92 718	19 220	73 498	14 512	161	52	32
1940–1959, district heating	92 465	19 220	73 245	14 630	160	52	32
1940–1959, geothermal heating	30 791	6 400	24 391	4 872	53	17	11
1960–1969, oil-heating	113 272	24 581	88 691	18 537	150	49	31
1960–1969, electrical heating	99 491	24 581	74 910	17 626	127	42	30
1960–1969, district heating	99 399	24 581	74 818	17 770	127	42	30
1960–1969, geothermal heating	33 100	8 185	24 914	5 917	42	14	10
1970–1979, oil-heating	92 613	22 332	70 281	18 037	132	43	34
1970–1979, electrical heating	81 952	22 332	59 620	17 262	112	37	33
1970–1979, district heating	81 246	22 332	58 914	17 340	111	36	33
1970–1979, geothermal heating	27 055	7 437	19 618	5 774	37	12	11
1980–1989, oil-heating	80 090	16 725	63 365	16 300	159	52	41
1980–1989, electrical heating	71 710	16 725	54 985	15 710	138	45	39
1980–1989, district heating	70 260	16 725	53 535	15 780	134	44	40
1980–1989, geothermal heating	23 397	5 569	17 827	5 255	45	15	13
1990–1999, oil-heating	71 510	15 916	55 594	16 120	153	48	44
1990–1999, electrical heating	64 010	15 916	48 094	15 560	132	41	43
1990–1999, district heating	62 730	15 916	46 814	15 620	129	40	43
1990–1999, geothermal heating	20 889	5 300	15 589	5 201	43	13	14
2000–2008, oil-heating	64 280	18 494	45 786	18 270	107	34	43
2000–2008, electrical heating	57 810	18 494	39 316	17 650	92	29	41
2000–2008, district heating	55 710	18 494	37 216	17 690	87	28	42
2000–2008, geothermal heating	18 551	6 159	12 393	5 891	29	9	14

Energy consumption of unrenovated residential blocks of flats.

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	303 647	72 645	231 002	29 870	174	44	23
–1920, district heating	269 636	72 645	196 991	27 600	149	37	21
1920–1939, oil-heating	315 375	78 266	237 109	37 100	148	42	23
1920–1939, district heating	279 970	78 266	201 704	35 940	126	35	22
1940–1959, oil-heating	257 974	63 076	194 898	37 520	149	42	29
1940–1959, district heating	229 112	63 076	166 036	35 440	127	36	27
1960–1969, oil-heating	352 560	82 145	270 415	60 030	148	45	33
1960–1969, district heating	312 915	82 145	230 770	57 460	126	39	31
1970–1979, oil-heating	342 083	87 355	254 728	60 570	137	40	33
1970–1979, district heating	303 662	87 355	216 307	57 840	116	34	31
1980–1989, oil-heating	236 059	62 130	173 929	42 290	131	38	32
1980–1989, district heating	209 560	62 130	147 430	40 350	111	33	30
1990–1999, oil-heating	232 240	62 596	169 644	43 550	127	37	33
1990–1999, district heating	206 341	62 596	143 745	41 590	108	31	31
2000–2008, oil-heating	241 160	104 670	136 490	66 890	75	22	37
2000–2008, district heating	211 610	104 670	106 940	64 270	59	18	35

b) Calculation results for buildings with passive-level envelope renovation

Energy consumption of detached houses with passive-level envelope renovation.

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	13 670	1 291	12 379	5 450	100	32	44,2
–1920, electrical heating	11 630	1 291	10 339	5 400	84	27	43,8
–1920, wood heating	16 600	1 291	15 309	5 450	124	40	44,2
–1920, district heating	11 860	1 291	10 569	5450	86	28	44,2
–1920, geothermal heating	3 949	430	3 519	1814,85	29	9	14,7
1920–1939, oil-heating	11 800	1 146	10 654	5 530	97	31	50,6
1920–1939, electrical heating	10 130	1 146	8 984	5 360	82	26	49,0
1920–1939, wood heating	14 510	1 146	13 364	5 390	122	39	49,3
1920–1939, district heating	10 370	1 146	9 224	5390	84	27	49,3
1920–1939, geothermal heating	3 453	382	3 072	1794,87	28	9	16,4
1940–1959, oil-heating	11 230	1 122	10 108	5 530	95	30	51,9
1940–1959, electrical heating	9 520	1 122	8 398	5 358	79	25	50,3
1940–1959, wood heating	13 850	1 122	12 728	5 390	119	38	50,6
1940–1959, district heating	9 750	1 122	8 628	5390	81	26	50,6
1940–1959, geothermal heating	3 247	374	2 873	1794,87	27	9	16,8
1960–1969, oil-heating	12 790	1 261	11 529	5 630	95	31	46,6
1960–1969, electrical heating	11 280	1 261	10 019	5 430	83	27	45,0
1960–1969, wood heating	16 120	1 261	14 859	5 460	123	40	45,2
1960–1969, district heating	11 510	1 261	10 249	5460	85	27	45,2
1960–1969, geothermal heating	3 833	420	3 413	1818,18	28	9	15,1
1970–1979, oil-heating	14 070	1 493	12 577	5 750	90	28	41,1
1970–1979, electrical heating	11 940	1 493	10 447	5 520	75	24	39,5
1970–1979, wood heating	17 310	1 493	15 817	5 550	113	36	39,7
1970–1979, district heating	12 190	1 493	10 697	5550	77	24	39,7
1970–1979, geothermal heating	4 059	497	3 562	1848,15	25	8	13,2
1980–1989, oil-heating	21 170	1 601	19 569	6 280	133	41	42,5
1980–1989, electrical heating	18 170	1 601	16 569	6 030	112	35	40,9
1980–1989, wood heating	26 090	1 601	24 489	6 060	166	52	41,1
1980–1989, district heating	18 370	1 601	16 769	6060	114	35	41,1
1980–1989, geothermal heating	6 117	533	5 584	2017,98	38	12	13,7
1990–1999, oil-heating	22 390	1 682	20 708	6 370	136	41	41,7
1990–1999, electrical heating	19 050	1 682	17 368	5 620	114	35	36,8
1990–1999, wood heating	26 250	1 682	24 568	6 820	161	49	44,7
1990–1999, district heating	19 200	1 682	17 518	6150	115	35	40,3

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
1990–1999, geothermal heating	6 394	560	5 833	2047,95	38	12	13,4
2000–2008, oil-heating	17 410	1 803	15 607	6 500	95	29	39,7
2000–2008, electrical heating	14 860	1 803	13 057	5 750	80	24	35,1
2000–2008, wood heating	21 190	1 803	19 387	6 500	118	36	39,7
2000–2008, district heating	14 920	1 803	13 117	6 280	80	24	38
2000–2008, geothermal heating	4 968	600	4 368	2 091	27	8	13

Energy consumption of attached houses with passive-level envelope renovation.

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	50 760	16 520	34 240	14 861	87	28	37,7
–1920, electrical heating	44 110	16 520	27 590	14 299	70	23	36,3
–1920, district heating	44 560	16 520	28 040	14350	71	23	36,4
–1920, geothermal heating	14 838	5 501	9 337	4778,55	24	8	12,1
1920–1939, oil-heating	44 450	14 669	29 781	14 592	86	28	42,1
1920–1939, electrical heating	39 030	14 669	24 361	14 020	70	23	40,4
1920–1939, district heating	39 010	14 669	24 341	14130	70	23	40,7
1920–1939, geothermal heating	12 990	4 885	8 106	4705,29	23	8	13,6
1940–1959, oil-heating	57 940	19 220	38 720	15 232	85	28	33,3
1940–1959, electrical heating	50 420	19 220	31 200	14 512	68	22	31,8
1940–1959, district heating	50 900	19 220	31 680	14630	69	23	32,0
1940–1959, geothermal heating	16 950	6 400	10 549	4871,79	23	8	10,7
1960–1969, oil-heating	73 370	24 581	48 789	18 537	83	27	31,4
1960–1969, electrical heating	63 880	24 581	39 299	17 626	67	22	29,9
1960–1969, district heating	64 380	24 581	39 799	17770	67	22	30,1
1960–1969, geothermal heating	21 439	8 185	13 253	5917,41	22	7	10,0
1970–1979, oil-heating	63 630	22 332	41 298	18 037	78	25	34,0
1970–1979, electrical heating	55 850	22 332	33 518	17 262	63	21	32,5
1970–1979, district heating	55 820	22 332	33 488	17340	63	21	32,7
1970–1979, geothermal heating	18 588	7 437	11 152	5774,22	21	7	10,9
1980–1989, oil-heating	60 960	16 725	44 235	16 300	111	36	40,9
1980–1989, electrical heating	54 270	16 725	37 545	15 710	94	31	39,4
1980–1989, district heating	53 480	16 725	36 755	15780	92	30	39,5
1980–1989, geothermal heating	17 809	5 569	12 239	5254,74	31	10	13,2
1990–1999, oil-heating	55 350	15 916	39 434	16 120	108	34	44,3
1990–1999, electrical heating	49 280	15 916	33 364	15 560	92	29	42,7
1990–1999, district heating	48 550	15 916	32 634	15620	90	28	42,9
1990–1999, geothermal heating	16 167	5 300	10 867	5201,46	30	9	14,3
2000–2008, oil-heating	50 350	18 494	31 856	18 270	75	24	42,9
2000–2008, electrical heating	45 040	18 494	26 546	17 650	62	20	41,4
2000–2008, district heating	43 640	18 494	25 146	17 690	59	19	42
2000–2008, geothermal heating	14 532	6 159	8 374	5 891	20	6	14

Energy consumption of residential blocks of flats with passive-level envelope renovation.

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	179 660	72 645	107 015	29 870	81	20	22,5
–1920, district heating	159 550	72 645	86 905	27 600	66	16	20,8
1920–1939, oil-heating	195 450	78 266	117 184	37 100	73	21	23,2
1920–1939, district heating	173 510	78 266	95 244	35940	60	17	22,5
1940–1959, oil-heating	152 000	63 076	88 924	37 520	68	19	28,7
1940–1959, district heating	135 010	63 076	71 934	35 440	55	16	27,1
1960–1969, oil-heating	271 300	82 145	189 155	60 030	104	32	32,9
1960–1969, district heating	240 780	82 145	158 635	57460	87	26	31,5
1970–1979, oil-heating	277 400	87 355	190 045	60 570	102	30	32,6
1970–1979, district heating	246 240	87 355	158 885	57840	86	25	31,1
1980–1989, oil-heating	195 610	62 130	133 480	42 290	100	29	31,8
1980–1989, district heating	173 650	62 130	111 520	40 350	84	25	30,4
1990–1999, oil-heating	195 670	62 596	133 074	43 550	100	29	32,6
1990–1999, district heating	173 860	62 596	111 264	41590	83	24	31,2
2000–2008, oil-heating	208 630	104 670	103 960	66 890	57	17	36,9
2000–2008, district heating	183 060	104 670	78 390	64 270	43	13	35

c) Calculation results for buildings with ventilation renovation

Energy consumptoin of detached houses, ventilation renovation

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	31 960	1 291	30 669	6 040	249	80	49,0
-1920, electrical heating	27 620	1 291	26 329	5 990	214	69	48,6
-1920, wood heating	38 810	1 291	37 519	6 040	305	98	49,0
–1920, district heating	27 720	1 291	26 429	6040	215	69	49,0
–1920, geothermal heating	9 231	430	8 801	2011,32	71	23	16,3
1920-1939, oil-heating	28 550	1 146	27 404	5 530	251	81	50,6
1920-1939, electrical heating	24 950	1 146	23 804	5 880	218	70	53,8
1920-1939, wood heating	35 080	1 146	33 934	5 910	310	100	54,1
1920-1939, district heating	25 060	1 146	23 914	5910	219	70	54,1
1920-1939, geothermal heating	8 345	382	7 963	1968,03	73	23	18,0
1940-1959, oil-heating	27 960	1 122	26 838	6 030	252	81	56,6
1940-1959, electrical heating	24 130	1 122	23 008	5 860	216	69	55,0
1940-1959, wood heating	34 440	1 122	33 318	5 890	313	100	55,3
1940-1959, district heating	24 250	1 122	23 128	5890	217	70	55,3
1940-1959, geothermal heating	8 075	374	7 702	1961,37	72	23	18,4
1960-1969, oil-heating	26 100	1 261	24 839	6 200	206	66	51,3
1960-1969, electrical heating	21 690	1 261	20 429	6 000	169	55	49,7
1960-1969, wood heating	30 560	1 261	29 299	6 030	243	78	49,9
1960-1969, district heating	21 830	1 261	20 569	6030	170	55	49,9
1960-1969, geothermal heating	7 269	420	6 849	2007,99	57	18	16,6
1970-1979, oil-heating	26 590	1 493	25 097	6 420	180	57	45,9
1970-1979, electrical heating	22 890	1 493	21 397	6 190	153	48	44,3
1970-1979, wood heating	32 780	1 493	31 287	6 220	224	71	44,5
1970-1979, district heating	23 080	1 493	21 587	6220	154	49	44,5
1970-1979, geothermal heating	7 686	497	7 188	2071,26	51	16	14,8
1980-1989, oil-heating	22 480	1 601	20 879	6 560	141	44	44,4
1980-1989, electrical heating	19 310	1 601	17 709	6 310	120	37	42,8
1980-1989, wood heating	27 690	1 601	26 089	6 340	177	55	43,0
1980-1989, district heating	19 490	1 601	17 889	6340	121	38	43,0
1980-1989, geothermal heating	6 490	533	5 957	2111,22	40	13	14,3
1990-1999, oil-heating	22 710	1 682	21 028	5 940	138	42	38,9
1990-1999, electrical heating	19 300	1 682	17 618	5 190	115	35	34,0
1990-1999, wood heating	26 570	1 682	24 888	6 390	163	50	41,9
1990-1999, district heating	22 710	1 682	21 028	5940	138	42	38,9

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
1990-1999, geothermal heating	7 562	560	7 002	1978,02	46	14	13,0
2000-2008, oil-heating	21 770	1 803	19 967	6 040	122	37	36,9
2000-2008, electrical heating	18 680	1 803	16 877	5 290	103	32	32,3
2000-2008, wood heating	26 500	1 803	24 697	6 040	151	46	36,9
2000-2008, district heating	18 680	1 803	16 877	5 820	103	32	36
2000-2008, geothermal heating	6 220	600	5 620	1 938	34	10	12

Energy consumption of attached houses, ventilation renovation

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	90 630	16 520	74 110	14 870	188	62	37,7
–1920, electrical heating	79 710	16 520	63 190	93 950	160	52	238,5
–1920, district heating	79 560	16 520	63 040	14 350	160	52	36,4
–1920, geothermal heating	26 493	5 501	20 992	4778,55	53	17	12,1
1920–1939, oil-heating	81 210	14 669	66 541	14 590	192	62	42,0
1920–1939, electrical heating	72 180	14 669	57 511	86 220	166	54	248,5
1920–1939, district heating	71 260	14 669	56 591	14 130	163	53	40,7
1920–1939, geothermal heating	23 730	4 885	18 845	4705,29	54	18	13,6
1940–1959, oil-heating	101 980	19 220	82 760	15 230	181	59	33,3
1940–1959, electrical heating	89 760	19 220	70 540	14 490	154	50	31,7
1940–1959, district heating	89 550	19 220	70 330	14 630	154	50	32,0
1940–1959, geothermal heating	29 820	6 400	23 420	4871,79	51	17	10,7
1960–1969, oil-heating	109 070	24 581	84 489	18 540	143	47	31,4
1960–1969, electrical heating	95 730	24 581	71 149	17 630	121	40	29,9
1960–1969, district heating	95 710	24 581	71 129	17 770	121	40	30,1
1960–1969, geothermal heating	31 871	8 185	23 686	5917,41	40	13	10,0
1970–1979, oil-heating	88 830	22 332	66 498	18 040	125	41	34,0
1970–1979, electrical heating	78 550	22 332	56 218	17 240	106	35	32,5
1970–1979, district heating	77 930	22 332	55 598	17 340	105	34	32,7
1970–1979, geothermal heating	25 951	7 437	18 514	5774,22	35	11	10,9
1980–1989, oil-heating	60 730	16 725	44 005	16 720	110	36	41,9
1980–1989, electrical heating	54 130	16 725	37 405	16 130	94	31	40,4
1980–1989, district heating	70 240	16 725	53 515	16 200	134	44	40,6
1980–1989, geothermal heating	23 390	5 569	17 820	5394,6	45	15	13,5
1990–1999, oil-heating	53 270	15 916	37 354	16 520	103	32	45,4
1990–1999, electrical heating	47 380	15 916	31 464	15 960	86	27	43,8
1990–1999, district heating	46 720	15 916	30 804	16 020	85	27	44,0
1990–1999, geothermal heating	15 558	5 300	10 258	5334,66	28	9	14,7
2000–2008, oil-heating	57 380	18 494	38 886	17 120	91	29	40,2
2000–2008, electrical heating	51 430	18 494	32 936	16 500	77	24	38,7
2000–2008, district heating	55 750	18 494	37 256	16 540	87	28	39
2000–2008, geothermal heating	18 565	6 159	12 406	5 508	29	9	13

Energy consumption of residential blocks of flats, ventilation renovation

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	278 530	72 645	205 885	39 120	155	39	29,5
–1920, district heating	247 310	72 645	174 665	36850	132	33	27,8
1920–1939, oil-heating	288 500	78 266	210 234	37 100	131	37	23,2
1920–1939, district heating	256 190	78 266	177 924	45920	111	31	28,7
1940–1959, oil-heating	236 360	63 076	173 284	37 520	133	38	28,7
1940–1959, district heating	209 920	63 076	146 844	35440	112	32	27,1
1960–1969, oil-heating	245 940	82 145	163 795	63 960	90	27	35,0
1960–1969, district heating	218 410	82 145	136 265	61390	75	23	33,6
1970–1979, oil-heating	230 480	87 355	143 125	64 750	77	22	34,8
1970–1979, district heating	204 710	87 355	117 355	62020	63	18	33,4
1980–1989, oil-heating	157 040	62 130	94 910	45 270	71	21	34,1
1980–1989, district heating	139 490	62 130	77 360	43330	58	17	32,6
1990–1999, oil-heating	153 460	62 596	90 864	45 340	68	20	34,0
1990–1999, district heating	136 150	62 596	73 554	43380	55	16	32,5
2000–2008, oil-heating	208 940	104 670	104 270	60 880	58	17	33,6
2000–2008, district heating	183 450	104 670	78 780	58 260	43	13	32

d) Calculation results for buildings with solar heat utilization

Energy consumption of detached houses, utilization of solar heat

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	32 229	646	31 583	5 450	256	82	44,2
–1920, electrical heating	27 785	646	27 139	5 400	220	71	43,8
–1920, wood heating	39 273	646	38 627	5 450	314	101	44,2
–1920, district heating	27 868	646	27 222	5450	221	71	44,2
–1920, geothermal heating	9 280	215	9 065	1814,85	74	24	14,7
1920–1939, oil-heating	28 791	573	28 218	5 530	258	83	50,6
1920–1939, electrical heating	25 107	573	24 534	5 360	224	72	49,0
1920–1939, wood heating	35 520	573	34 947	5 390	320	103	49,3
1920–1939, district heating	25 208	573	24 635	5390	225	72	49,3
1920–1939, geothermal heating	8 394	191	8 203	1794,87	75	24	16,4
1940–1959, oil-heating	28 194	561	27 633	5 530	259	83	51,9
1940–1959, electrical heating	24 288	561	23 727	5 358	223	71	50,3
1940–1959, wood heating	34 880	561	34 319	5 390	322	103	50,6
1940–1959, district heating	24 392	561	23 831	5390	224	72	50,6
1940–1959, geothermal heating	8 123	187	7 936	1794,87	74	24	16,8
1960–1969, oil-heating	26 324	631	25 693	5 630	213	69	46,6
1960–1969, electrical heating	21 827	631	21 196	5 430	175	57	45,0
1960–1969, wood heating	30 995	631	30 364	5 460	251	81	45,2
1960–1969, district heating	21 959	631	21 328	5460	177	57	45,2
1960–1969, geothermal heating	7 312	210	7 102	1818,18	59	19	15,1
1970–1979, oil-heating	26 930	747	26 183	5 750	187	59	41,1
1970–1979, electrical heating	23 085	747	22 338	5 520	160	50	39,5
1970–1979, wood heating	33 315	747	32 568	5 550	233	73	39,7
1970–1979, district heating	23 236	747	22 489	5550	161	51	39,7
1970–1979, geothermal heating	7 737	249	7 489	1848,15	54	17	13,2
1980–1989, oil-heating	29 456	801	28 655	6 350	194	60	43,0
1980–1989, electrical heating	25 323	801	24 522	6 100	166	52	41,3
1980–1989, wood heating	36 473	801	35 672	6 130	242	75	41,5
1980–1989, district heating	25 443	801	24 642	6130	167	52	41,5
1980–1989, geothermal heating	8 472	267	8 206	2041,29	56	17	13,8
1990–1999, oil-heating	30 196	841	29 355	6 540	192	59	42,9
1990–1999, electrical heating	25 668	841	24 827	5 790	163	50	37,9
1990–1999, wood heating	35 860	841	35 019	6 990	229	70	45,8
1990–1999, district heating	25 767	841	24 926	6320	163	50	41,4

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
1990–1999, geothermal heating	8 580	280	8 300	2104,56	54	17	13,8
2000–2008, oil-heating	23 859	902	22 957	6 500	140	43	39,7
2000–2008, electrical heating	20 379	902	19 477	5 750	119	36	35,1
2000–2008, wood heating	29 239	902	28 337	6 500	173	53	39,7
2000–2008, district heating	20 319	902	19 417	6 280	119	36	38
2000–2008, geothermal heating	6 766	300	6 466	2 091	39	12	13

Energy consumption of attached houses, utilization of solar heat

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	85 208	8 260	76 948	14 861	195	64	37,7
–1920, electrical heating	73 992	8 260	65 732	14 299	167	55	36,3
–1920, district heating	73 785	8 260	65 525	14350	166	54	36,4
–1920, geothermal heating	24 570	2 751	21 820	4778,55	55	18	12,1
1920–1939, oil-heating	76 400	7 335	69 065	14 592	199	65	42,1
1920–1939, electrical heating	67 148	7 335	59 813	14 020	172	56	40,4
1920–1939, district heating	66 150	7 335	58 815	14130	169	55	40,7
1920–1939, geothermal heating	22 028	2 442	19 585	4705,29	56	18	13,6
1940–1959, oil-heating	95 684	9 610	86 074	15 232	188	61	33,3
1940–1959, electrical heating	83 108	9 610	73 498	14 512	161	52	31,8
1940–1959, district heating	82 855	9 610	73 245	14630	160	52	32,0
1940–1959, geothermal heating	27 591	3 200	24 391	4871,79	53	17	10,7
1960–1969, oil-heating	100 982	12 291	88 691	18 537	150	49	31,4
1960–1969, electrical heating	87 201	12 291	74 910	17 626	127	42	29,9
1960–1969, district heating	87 109	12 291	74 818	17770	127	42	30,1
1960–1969, geothermal heating	29 007	4 093	24 914	5917,41	42	14	10,0
1970–1979, oil-heating	81 447	11 166	70 281	18 037	132	43	34,0
1970–1979, electrical heating	70 786	11 166	59 620	17 262	112	37	32,5
1970–1979, district heating	70 080	11 166	58 914	17340	111	36	32,7
1970–1979, geothermal heating	23 337	3 718	19 618	5774,22	37	12	10,9
1980–1989, oil-heating	71 844	8 363	63 481	16 530	159	52	41,4
1980–1989, electrical heating	63 535	8 363	55 172	15 940	138	45	39,9
1980–1989, district heating	61 997	8 363	53 634	16010	134	44	40,1
1980–1989, geothermal heating	20 645	2 785	17 860	5331,33	45	15	13,4
1990–1999, oil-heating	63 471	7 958	55 513	16 330	153	48	44,9
1990–1999, electrical heating	55 986	7 958	48 028	15 770	132	41	43,3
1990–1999, district heating	54 697	7 958	46 739	15830	128	40	43,5
1990–1999, geothermal heating	18 214	2 650	15 564	5271,39	43	13	14,5
2000–2008, oil-heating	55 033	9 247	45 786	18 270	107	34	42,9
2000–2008, electrical heating	48 563	9 247	39 316	17 650	92	29	41,4
2000–2008, district heating	46 463	9 247	37 216	17 690	87	28	41,5
2000–2008, geothermal heating	15 472	3 079	12 393	5 891	29	9	14

Energy consumption of residential blocks of flats, utilization of solar heat

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	267 325	36 323	231 002	29 870	174	44	22,5
–1920, district heating	233 314	36 323	196 991	27600	149	37	20,8
1920–1939, oil-heating	276 242	39 133	237 109	37 100	148	42	23,2
1920–1939, district heating	240 837	39 133	201 704	35940	126	35	22,5
1940–1959, oil-heating	226 436	31 538	194 898	37 520	149	42	28,7
1940–1959, district heating	197 574	31 538	166 036	35440	127	36	27,1
1960–1969, oil-heating	311 488	41 073	270 415	60 030	148	45	32,9
1960–1969, district heating	271 843	41 073	230 770	57460	126	39	31,5
1970–1979, oil-heating	298 406	43 678	254 728	60 570	137	40	32,6
1970–1979, district heating	259 985	43 678	216 307	57840	116	34	31,1
1980–1989, oil-heating	204 994	31 065	173 929	42 290	131	38	31,8
1980–1989, district heating	178 495	31 065	147 430	40350	111	33	30,4
1990–1999, oil-heating	200 942	31 298	169 644	43 550	127	37	32,6
1990–1999, district heating	175 043	31 298	143 745	41590	108	31	31,2
2000–2008, oil-heating	188 825	52 335	136 490	66 890	75	22	36,9
2000–2008, district heating	159 275	52 335	106 940	64 270	59	18	35

e) Calculation results for buildings with window renovation

Energy consumption of detached houses, window renovation.

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	29 180	1 291	27 889	5 450	226,4	72,8	44,2
–1920, electrical heating	25 200	1 291	23 909	5 400	194,1	62,4	43,8
–1920, wood heating	35 440	1 291	34 149	5 450	277,2	89,1	44,2
–1920, district heating	25 310	1 291	24 019	5 450	195,0	62,7	44,2
–1920, geothermal heating	8 428	430	7 998	1 815	64,9	20,9	14,7
1920–1939, oil-heating	26 120	1 146	24 974	5 530	228,5	73,5	50,6
1920–1939, electrical heating	22 810	1 146	21 664	5 360	198,2	63,7	49,0
1920–1939, wood heating	32 110	1 146	30 964	5 390	283,3	91,1	49,3
1920–1939, district heating	22 940	1 146	21 794	5 390	199,4	64,1	49,3
1920–1939, geothermal heating	7 639	382	7 257	1 795	66,4	21,4	16,4
1940–1959, oil-heating	25 980	1 122	24 858	5 530	233,2	74,7	51,9
1940–1959, electrical heating	22 420	1 122	21 298	5 360	199,8	64,0	50,3
1940–1959, wood heating	32 030	1 122	30 908	5 390	289,9	92,9	50,6
1940–1959, district heating	22 550	1 122	21 428	5 390	201,0	64,4	50,6
1940–1959, geothermal heating	7 509	374	7 136	1 795	66,9	21,5	16,8
1960–1969, oil-heating	23 370	1 261	22 109	5 630	183,0	59,1	46,6
1960–1969, electrical heating	19 320	1 261	18 059	5 430	149,5	48,2	45,0
1960–1969, wood heating	27 270	1 261	26 009	5 460	215,3	69,5	45,2
1960–1969, district heating	19 480	1 261	18 219	5 460	150,8	48,7	45,2
1960–1969, geothermal heating	6 487	420	6 067	1 818	50,2	16,2	15,1
1970–1979, oil-heating	24 490	1 493	22 997	5 750	164,5	51,9	41,1
1970–1979, electrical heating	21 040	1 493	19 547	5 520	139,8	44,1	39,5
1970–1979, wood heating	30 140	1 493	28 647	5 550	204,9	64,6	39,7
1970–1979, district heating	21 220	1 493	19 727	5 550	141,1	44,5	39,7
1970–1979, geothermal heating	7 066	497	6 569	1 848	47,0	14,8	13,2
1980–1989, oil-heating	28 050	1 601	26 449	6 330	179,2	55,6	42,9
1980–1989, electrical heating	24 190	1 601	22 589	6 080	153,0	47,5	41,2
1980–1989, wood heating	34 550	1 601	32 949	6 110	223,2	69,3	41,4
1980–1989, district heating	24 500	1 601	22 899	6 290	155,1	48,2	42,6
1980–1989, geothermal heating	8 159	533	7 625	2 095	51,7	16,0	14,2
1990–1999, oil-heating	28 710	1 682	27 028	6 500	177,1	54,2	42,6
1990–1999, electrical heating	24 500	1 682	22 818	5 750	149,5	45,7	37,7
1990–1999, wood heating	33 880	1 682	32 198	6 950	211,0	64,5	45,5
1990–1999, district heating	24 610	1 682	22 928	6 280	150,2	45,9	41,2

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
1990–1999, geothermal heating	8 195	560	7 635	2 091	50,0	15,3	13,7
2000–2008, oil-heating	21 860	1 803	20 057	6 630	122,5	37,5	40,5
2000–2008, electrical heating	18 780	1 803	16 977	5 880	103,7	31,7	35,9
2000–2008, wood heating	26 620	1 803	24 817	6 630	151,6	46,4	40,5
2000–2008, district heating	18 740	1 803	16 937	6 410	103,5	31,6	39,2
2000–2008, geothermal heating	6 240	600	5 640	2 135	34,5	10,5	13,0

Energy consumption of attached houses, window renovation.

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	82 010	16 520	65 490	14 870	166,2	54,3	37,7
–1920, electrical heating	72 000	16 520	55 480	14 240	140,8	46,0	36,1
–1920, district heating	71 990	16 520	55 470	14 350	140,8	46,0	36,4
–1920, geothermal heating	23 973	5 501	18 472	4 779	46,9	15,3	12,1
1920–1939, oil-heating	73 650	14 669	58 981	14 590	170,0	55,1	42,0
1920–1939, electrical heating	65 350	14 669	50 681	14 040	146,1	47,4	40,5
1920–1939, district heating	64 630	14 669	49 961	14 130	144,0	46,7	40,7
1920–1939, geothermal heating	21 522	4 885	16 637	4 705	47,9	15,5	13,6
1940–1959, oil-heating	93 780	19 220	74 560	15 230	163,2	53,2	33,3
1940–1959, electrical heating	82 430	19 220	63 210	14 490	138,3	45,1	31,7
1940–1959, district heating	82 360	19 220	63 140	14 630	138,2	45,0	32,0
1940–1959, geothermal heating	27 426	6 400	21 026	4 872	46,0	15,0	10,7
1960–1969, oil-heating	98 650	24 581	74 069	18 540	125,5	41,3	31,4
1960–1969, electrical heating	86 420	24 581	61 839	17 630	104,8	34,5	29,9
1960–1969, district heating	86 560	24 581	61 979	17 770	105,0	34,6	30,1
1960–1969, geothermal heating	28 824	8 185	20 639	5 917	35,0	11,5	10,0
1970–1979, oil-heating	82 620	22 332	60 288	18 040	113,5	37,0	34,0
1970–1979, electrical heating	72 940	22 332	50 608	17 260	95,3	31,1	32,5
1970–1979, district heating	72 480	22 332	50 148	17 340	94,4	30,8	32,7
1970–1979, geothermal heating	24 136	7 437	16 699	5 774	31,4	10,3	10,9
1980–1989, oil-heating	73 990	16 725	57 265	16 450	143,5	46,9	41,2
1980–1989, electrical heating	66 230	16 725	49 505	15 860	124,1	40,6	39,7
1980–1989, district heating	64 990	16 725	48 265	15 930	121,0	39,6	39,9
1980–1989, geothermal heating	21 642	5 569	16 072	5 305	40,3	13,2	13,3
1990–1999, oil-heating	66 020	15 916	50 104	16 270	137,6	43,2	44,7
1990–1999, electrical heating	59 000	15 916	43 084	15 710	118,4	37,1	43,2
1990–1999, district heating	57 910	15 916	41 994	15 770	115,4	36,2	43,3
1990–1999, geothermal heating	19 284	5 300	13 984	5 251	38,4	12,0	14,4
2000–2008, oil-heating	58 800	18 494	40 306	18 270	94,6	29,9	42,9
2000–2008, electrical heating	52 780	18 494	34 286	17 650	80,5	25,4	41,4
2000–2008, district heating	50 960	18 494	32 466	17 690	76,2	24,1	41,5
2000–2008, geothermal heating	16 970	6 159	10 811	5 891	25,4	8,0	13,8

Energy consumption of residential blocks of flats, window renovation.

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	266 040	72 645	193 395	29 870	146,0	36,5	22,5
–1920, district heating	236 240	72 645	163 595	27 600	123,5	30,9	20,8
1920–1939, oil-heating	270 500	78 266	192 234	37 100	120,2	33,7	23,2
1920–1939, district heating	240 130	78 266	161 864	35 940	101,2	28,4	22,5
1940–1959, oil-heating	226 250	63 076	163 174	37 520	124,8	35,5	28,7
1940–1959, district heating	200 940	63 076	137 864	35 440	105,5	30,0	27,1
1960–1969, oil-heating	307 960	82 145	225 815	60 320	123,6	37,7	33,0
1960–1969, district heating	273 600	82 145	191 455	57 750	104,8	32,0	31,6
1970–1979, oil-heating	307 390	87 355	220 035	60 880	118,4	34,5	32,8
1970–1979, district heating	272 860	87 355	185 505	58 150	99,8	29,1	31,3
1980–1989, oil-heating	216 210	62 130	154 080	42 510	115,9	34,0	32,0
1980–1989, district heating	191 940	62 130	129 810	40 570	97,7	28,6	30,5
1990–1999, oil-heating	212 570	62 596	149 974	43 820	112,3	32,8	32,8
1990–1999, district heating	188 660	62 596	126 064	41 860	94,4	27,6	31,4
2000–2008, oil-heating	217 290	104 670	112 620	67 610	62,2	18,4	37,3
2000–2008, district heating	190 650	104 670	85 980	64 990	47,5	14,1	35,9

f) Calculation results for buildings with a combination of renovations

Energy consumption of detached houses, a combination of renovations.

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	8 560	646	7 915	6 020	64,2	20,7	48,9
–1920, electrical heating	7 160	646	6 515	5 970	52,9	17,0	48,5
–1920, wood heating	10 390	646	9 745	6 020	79,1	25,4	48,9
–1920, district heating	7 420	646	6 775	6 020	55,0	17,7	48,9
–1920, geothermal heating	2 471	215	2 256	2 005	18,3	5,9	16,3
1920–1939, oil-heating	7 560	573	6 987	5 530	63,9	20,6	50,6
1920–1939, electrical heating	6 390	573	5 817	5 930	53,2	17,1	54,3
1920–1939, wood heating	9 300	573	8 727	5 960	79,8	25,7	54,5
1920–1939, district heating	6 640	573	6 067	5 960	55,5	17,8	54,5
1920–1939, geothermal heating	2 211	191	2 020	1 985	18,5	5,9	18,2
1940–1959, oil-heating	7 430	561	6 869	6 090	64,4	20,7	57,1
1940–1959, electrical heating	6 220	561	5 659	5 920	53,1	17,0	55,5
1940–1959, wood heating	9 160	561	8 599	5 950	80,7	25,9	55,8
1940–1959, district heating	6 450	561	5 889	5 950	55,2	17,7	55,8
1940–1959, geothermal heating	2 148	187	1 961	1 981	18,4	5,9	18,6
1960–1969, oil-heating	8 130	631	7 500	6 260	62,1	20,0	51,8
1960–1969, electrical heating	7 170	631	6 540	6 060	54,1	17,5	50,2
1960–1969, wood heating	10 380	631	9 750	6 090	80,7	26,0	50,4
1960–1969, district heating	7 420	631	6 790	6 090	56,2	18,1	50,4
1960–1969, geothermal heating	2 471	210	2 261	2 028	18,7	6,0	16,8
1970–1979, oil-heating	9 460	747	8 714	6 490	62,3	19,7	46,4
1970–1979, electrical heating	7 930	747	7 184	6 260	51,4	16,2	44,8
1970–1979, wood heating	11 670	747	10 924	6 290	78,1	24,6	45,0
1970–1979, district heating	8 220	747	7 474	6 290	53,5	16,9	45,0
1970–1979, geothermal heating	2 737	249	2 489	2 095	17,8	5,6	15,0
1980–1989, oil-heating	10 500	801	9 700	6 630	65,7	20,4	44,9
1980–1989, electrical heating	8 850	801	8 050	6 380	54,5	16,9	43,2
1980–1989, wood heating	12 930	801	12 130	6 410	82,2	25,5	43,4
1980–1989, district heating	9 100	801	8 300	6 410	56,2	17,5	43,4
1980–1989, geothermal heating	3 030	267	2 764	2 135	18,7	5,8	14,5
1990–1999, oil-heating	11 110	841	10 269	6 030	67,3	20,6	39,5
1990–1999, electrical heating	9 280	841	8 439	5 280	55,3	16,9	34,6
1990–1999, wood heating	12 690	841	11 849	6 950	77,6	23,7	45,5
1990–1999, district heating	9 510	841	8 669	5 810	56,8	17,4	38,1

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
1990–1999, geothermal heating	3 167	280	2 887	1 935	18,9	5,8	12,7
2000–2008, oil-heating	11 510	902	10 609	6 120	64,8	19,8	37,4
2000–2008, electrical heating	9 730	902	8 829	5 370	53,9	16,5	32,8
2000–2008, wood heating	14 010	902	13 109	6 120	80,1	24,5	37,4
2000–2008, district heating	9 880	902	8 979	5 900	54,8	16,8	36,0
2000–2008, geothermal heating	3 290	300	2 990	1 965	18,3	5,6	12,0

Energy consumption of attached houses, a combination of renovations.

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	36 530	8 260	28 270	14 870	71,8	23,5	37,7
–1920, electrical heating	31 510	8 260	23 250	14 240	59,0	19,3	36,1
–1920, district heating	32 070	8 260	23 810	14 350	60,4	19,8	36,4
–1920, geothermal heating	10 679	2 751	7 929	4 779	20,1	6,6	12,1
1920–1939, oil-heating	32 070	7 335	24 736	14 590	71,3	23,1	42,0
1920–1939, electrical heating	27 940	7 335	20 606	14 040	59,4	19,3	40,5
1920–1939, district heating	28 150	7 335	20 816	14 130	60,0	19,5	40,7
1920–1939, geothermal heating	9 374	2 442	6 932	4 705	20,0	6,5	13,6
1940–1959, oil-heating	42 840	9 610	33 230	15 230	72,7	23,7	33,3
1940–1959, electrical heating	37 040	9 610	27 430	14 490	60,0	19,6	31,7
1940–1959, district heating	37 630	9 610	28 020	14 630	61,3	20,0	32,0
1940–1959, geothermal heating	12 531	3 200	9 331	4 872	20,4	6,7	10,7
1960–1969, oil-heating	57 310	12 291	45 020	18 540	76,3	25,1	31,4
1960–1969, electrical heating	49 620	12 291	37 330	17 630	63,3	20,8	29,9
1960–1969, district heating	50 290	12 291	38 000	17 770	64,4	21,2	30,1
1960–1969, geothermal heating	16 747	4 093	12 654	5 917	21,4	7,1	10,0
1970–1979, oil-heating	52 060	11 166	40 894	18 040	77,0	25,1	34,0
1970–1979, electrical heating	45 490	11 166	34 324	17 240	64,6	21,1	32,5
1970–1979, district heating	45 670	11 166	34 504	17 340	65,0	21,2	32,7
1970–1979, geothermal heating	15 208	3 718	11 490	5 774	21,6	7,1	10,9
1980–1989, oil-heating	35 900	8 363	27 538	16 910	69,0	22,6	42,4
1980–1989, electrical heating	31 610	8 363	23 248	16 320	58,3	19,1	40,9
1980–1989, district heating	31 480	8 363	23 118	16 390	57,9	18,9	41,1
1980–1989, geothermal heating	10 483	2 785	7 698	5 458	19,3	6,3	13,7
1990–1999, oil-heating	32 230	7 958	24 272	16 700	66,7	20,9	45,9
1990–1999, electrical heating	28 350	7 958	20 392	16 140	56,0	17,6	44,3
1990–1999, district heating	28 270	7 958	20 312	16 200	55,8	17,5	44,5
1990–1999, geothermal heating	9 414	2 650	6 764	5 395	18,6	5,8	14,8
2000–2008, oil-heating	37 490	9 247	28 243	17 330	66,3	20,9	40,7
2000–2008, electrical heating	33 360	9 247	24 113	16 710	56,6	17,9	39,2
2000–2008, district heating	32 510	9 247	23 263	16 750	54,6	17,2	39,3
2000–2008, geothermal heating	10 826	3 079	7 747	5 578	18,2	5,7	13,1

Energy consumption of residential blocks of flats, a combination of renovations.

	Total heating energy, kWh / a	Service water heating energy, kWh / a	Room heating energy, kWh / a	Device Electricity use kWh/a	Room heating energy, kWh / m^2,a	Room heating energy, kWh / m^3,a	Device Electricity use kWh/brm^2, a
–1920, oil-heating	123 930	36 323	87 608	39 540	66,1	16,5	29,8
–1920, district heating	109 950	36 323	73 628	37 270	55,6	13,9	28,1
1920–1939, oil-heating	132 350	39 133	93 217	37 100	58,3	16,3	23,2
1920–1939, district heating	117 560	39 133	78 427	46 350	49,0	13,7	29,0
1940–1959, oil-heating	106 270	31 538	74 732	37 520	57,2	16,2	28,7
1940–1959, district heating	94 370	31 538	62 832	35 440	48,1	13,7	27,1
1960–1969, oil-heating	136 060	41 073	94 988	64 420	52,0	15,9	35,3
1960–1969, district heating	120 700	41 073	79 628	61 850	43,6	13,3	33,9
1970–1979, oil-heating	144 490	43 678	100 813	65 240	54,3	15,8	35,1
1970–1979, district heating	128 200	43 678	84 523	62 510	45,5	13,3	33,6
1980–1989, oil-heating	104 460	31 065	73 395	45 610	55,2	16,2	34,3
1980–1989, district heating	92 770	31 065	61 705	43 670	46,4	13,6	32,9
1990–1999, oil-heating	104 370	31 298	73 072	45 690	54,7	16,0	34,2
1990–1999, district heating	92 690	31 298	61 392	43 730	46,0	13,4	32,8
2000–2008, oil-heating	160 340	52 335	108 005	61 340	59,6	17,7	33,9
2000–2008, district heating	140 660	52 335	88 325	58 720	48,7	14,5	32,4

Appendix C: Size of the building stock of 2010, and its renovation needs, by 2020 and 2030

This section presents size development of the residential housing stock of 2010, and its renovation needs by years 2020 and 2030.

a) Reduction in the size of the building stock of 2010, by 2020 and 2020

This appendix shows how the size of the building stock of 2010 will develop by 2020 and 2030.
The size of the building stock in 2010, 2020 and 2030, for detached houses. Unit $1000m^2$.

Building Year	2010	2020	2030
–1920	9640	8870	8120
1921–1939	7340	6600	5670
1940–1959	25080	22570	19380
1960–1969	13770	12770	11040
1970–1979	23620	22710	20160
1980–1989	28260	27690	25380
1990–1999	16860	16770	15800
2000–2008	22590	22590	21800
Sum	147200	140600	127400

Reduction in the floor area of detached houses between 2010 and 2020, and from 2020 to 2030.

Building Year	2010–2020	2020–2030
–1920	-8%	-8%
1921–1939	-10%	-14%
1940–1959	-10%	-14%
1960–1969	-7%	-14%
1970–1979	-4%	-11%
1980–1989	-2,0%	-8%
1990–1999	-0,5%	-6%
2000–2008	0%	-3%
Average	-4%	-9%

The size of the building stock in 2010, 2020 and 2030, for attached houses. Unit $1000m^2$.

Building Year	2010	2020	2030
–1920	540	430	380
1921–1939	140	110	90
1940–1959	500	400	340
1960–1969	2020	1860	1600
1970–1979	7850	7450	6590
1980–1989	11590	11300	10340
1990–1999	4720	4650	4370
2000–2008	3950	3940	3790
Sum	31300	30100	27500

Reduction in the floor area of attached houses between 2010 and 2020, and from 2020 to 2030.

Building Year	2010–2020	2020–2030
–1920	-20%	-12%
1921–1939	-21%	-18%
1940–1959	-20%	-15%
1960–1969	-8%	-14%
1970–1979	-5%	-12%
1980–1989	-2,5%	-8%
1990–1999	-1,5%	-6%
2000–2008	0%	-4%
Average	-4%	-9%

The size of the building stock in 2010, 2020 and 2030, for residential blocks of flats. Unit $1000m^2$.

Building Year	2010	2020	2030
–1920	2800	2600	2390
1921–1939	4670	4080	3580
1940–1959	9350	8810	7870
1960–1969	16690	16360	14770
1970–1979	22230	22000	20220
1980–1989	12170	12110	11230
1990–1999	10460	10410	9920
2000–2008	9320	9320	9120
Sum	87700	85700	79100

Reduction in the floor area of residential blocks of flats between 2010 and 2020, and from 2020 to 2030.

Building Year	2010–2020	2020–2030
–1920	-7%	-8%
1921–1939	-13%	-12%
1940–1959	-6%	-11%
1960–1969	-2%	-10%
1970–1979	-1%	-8%
1980–1989	-0,5%	-7%
1990–1999	-0,5%	-5%
2000–2008	0%	-2%
Average	-2%	-8%

The size of the building stock in 2010, 2020 and 2030. Unit $1000m^2$.

Building Year	2010	2020	2030
–1920	12980	11900	10890
1921–1939	12150	10790	9340
1940–1959	34930	31780	27590
1960–1969	32480	30990	27410
1970–1979	53700	52160	46970
1980–1989	52020	51100	46950
1990–1999	32040	31830	30090
2000–2008	35860	35850	34710
Sum	266200	256400	234000

Reduction in the floor area on building stock level between 2010 and 2020, and from 2020 to 2030.

Building Year	2010–2020	2020–2030
–1920	-8%	-8%
1921–1939	-11%	-13%
1940–1959	-9%	-13%
1960–1969	-5%	-12%
1970–1979	-3%	-10%
1980–1989	-1,8%	-8%
1990–1999	-0,7%	-5%
2000–2008	0%	-3%
Average	-4%	-9%

b) Need of thorough renovations in the Finnish residential housing stock of 2010

The following tables show the renovation need for residential buildings, in terms of number of buildings in need of thorough renovations between 2010 and 2020, and 2020 and 2030.

Renovation needs of residential buildings, thorough renovations, number of bulidings in need of renovation, 2010–2020.

Building Year	Detached houses	Attached houses	Residential blocks of flats
–1920	15000	200	400
1921–1939	17300	100	700
1940–1959	74400	200	1600
1960–1969	37800	700	1900
1970–1979	47400	3000	3800
1980–1989	45400	5900	2300
1990–1999	25400	4500	800
2000–2008	-	-	-
Sum	262700	14600	11500

Renovation needs of residential buildings, thorough renovations, number of buildings in need of renovation, 2020–2030.

Building Year	Detached houses	Attached houses	Residential blocks of flats
–1920	13000	100	300
1921–1939	13700	100	500
1940–1959	53400	200	1300
1960–1969	31700	600	1800
1970–1979	46000	2900	2800
1980–1989	69700	6000	2900
1990–1999	30300	3600	1900
2000–2008	25000	1900	500
Sum	282800	15400	12000

The renovation need of the building stock 2020 and 2030, for detached houses. Unit 1000m^2.

Building Year	Refurbishment need	
	Need in 2020	Need in 2030
–1920	2227	1920
1921–1939	1857	1470
1940–1959	7587	5443
1960–1969	4369	3670
1970–1979	6978	6761
1980–1989	6359	9767
1990–1999	3372	4025
2000–2008	0	4518
Sum	32749	37574

The relative share of floor area in need of renovations in 2020 and 2030, detached houses

Building Year	Refurbishment need	
	Share in 2020	Share in 2030
–1920	25%	24%
1921–1939	28%	26%
1940–1959	34%	28%
1960–1969	34%	33%
1970–1979	31%	34%
1980–1989	23%	38%
1990–1999	20%	25%
2000–2008	0%	21%
Average	23%	29%

The renovation need of the building stock 2020 and 2030, for attached houses. Unit 1000m^2.

Building Year	Refurbishment need	
	Need in 2020	Need in 2030
–1920	132	85
1921–1939	34	22
1940–1959	102	84
1960–1969	412	391
1970–1979	1601	1565
1980–1989	2364	2373
1990–1999	1346	1054
2000–2008	0	788
Sum	5991	6362

The relative share of floor area in need of renovations in 2020 and 2030, attached houses.

Building Year	Refurbishment need	
	Need in 2020	Need in 2030
–1920	31%	22%
1921–1939	31%	24%
1940–1959	26%	25%
1960–1969	22%	24%
1970–1979	21%	24%
1980–1989	21%	23%
1990–1999	29%	24%
2000–2008	0%	21%
Average	20%	23%

The renovation need of the building stock 2020 and 2030, for residential blocks of flats. Unit $1000m^2$.

Building Year	Refurbishment need	
	Need in 2020	Need in 2030
–1920	619	497
1921–1939	1032	779
1940–1959	2095	1738
1960–1969	3641	3451
1970–1979	6591	4928
1980–1989	3088	3856
1990–1999	1046	2486
2000–2008	0	932
Sum	18112	18667

The relative share of floor area in need of renovations in 2020 and 2030, residential blocks of flats.

Building Year	Refurbishment need	
	Share in 2020	Share in 2030
–1920	24%	21%
1921–1939	25%	22%
1940–1959	24%	22%
1960–1969	22%	23%
1970–1979	30%	24%
1980–1989	25%	34%
1990–1999	10%	25%
2000–2008	0%	10%
Average (all age groups)	21%	24%

The total renovation need of the building stock 2020 and 2030, for all residential buildings. Unit 1000m^2.

Building Year	Refurbishment need	
	Need in 2020	Need in 2030
–1920	2978	2502
1921–1939	2923	2271
1940–1959	9784	7265
1960–1969	8422	7512
1970–1979	15170	13254
1980–1989	11811	15996
1990–1999	5764	7565
2000–2008	0	6238
Sum	18112	18667

The relative share of total floor area in need of renovations in 2020 and 2030, all residential buildings.

Building Year	Refurbishment need	
	Share in 2020	Share in 2030
–1920	25%	23%
1921–1939	27%	24%
1940–1959	31%	26%
1960–1969	27%	27%
1970–1979	29%	28%
1980–1989	23%	34%
1990–1999	18%	25%
2000–2008	0%	18%
Average	22%	27%

c) Future need of light renovations in the Finnish residential housing stock

The following tables show the need for light renovations for building stock of 2010 in 2020 and 2030 for detached houses, attached houses and for residential blocks of flats.

The renovation need of the building stock 2020 and 2030, for detached houses. Unit 1000m^2.

Building Year	Refurbishment need	
	Need in 2020	Need in 2030
–1920	2747	2362
1921–1939	2006	1636
1940–1959	6025	4770
1960–1969	2865	2365
1970–1979	4940	4485
1980–1989	6067	5782
1990–1999	4732	4687
2000–2008	0	9036
Sum	29382	35123

The relative share of floor area in need of renovations in 2020 and 2030, detached houses.

Building Year	Refurbishment need	
	Share in 2020	Share in 2030
–1920	31%	29%
1921–1939	30%	29%
1940–1959	27%	25%
1960–1969	22%	21%
1970–1979	22%	22%
1980–1989	22%	23%
1990–1999	28%	30%
2000–2008	0%	41%
Average	21%	27%

The renovation need of the building stock 2020 and 2030, for attached houses. Unit 1000m^2.

Building Year	Refurbishment need	
	Need in 2020	Need in 2030
–1920	162	107
1921–1939	42	27
1940–1959	157	107
1960–1969	609	529
1970–1979	2342	2142
1980–1989	3427	3282
1990–1999	1160	1125
2000–2008	0	1576
Sum	7899	8895

The relative share of floor area in need of renovations in 2020 and 2030, attached houses.

Building Year	Refurbishment need	
	Need in 2020	Need in 2030
–1920	38%	28%
1921–1939	38%	30%
1940–1959	39%	31%
1960–1969	33%	33%
1970–1979	31%	33%
1980–1989	30%	32%
1990–1999	25%	26%
2000–2008	0%	42%
Average	26%	32%

The renovation need of the building stock 2020 and 2030, for residential blocks of flats. Unit 1000m^2.

Building Year	Refurbishment need	
	Need in 2020	Need in 2030
–1920	842	742
1921–1939	1429	1134
1940–1959	2759	2489
1960–1969	4799	4634
1970–1979	5355	5240
1980–1989	2613	2583
1990–1999	3464	3439
2000–2008	0	4194
Sum	21261	24455

The relative share of floor area in need of renovations in 2020 and 2030, residential blocks of flats.

Building Year	Refurbishment need	
	Share in 2020	Share in 2030
–1920	32%	31%
1921–1939	35%	32%
1940–1959	31%	32%
1960–1969	29%	31%
1970–1979	24%	26%
1980–1989	22%	23%
1990–1999	33%	35%
2000–2008	0%	46%
Average	25%	31%

The total renovation need of the building stock 2020 and 2030, for all residential buildings. Unit 1000m^2.

Building Year	Refurbishment need	
	Need in 2020	Need in 2030
–1920	3751	3211
1921–1939	3477	2797
1940–1959	8941	7366
1960–1969	8273	7528
1970–1979	12637	11867
1980–1989	12107	11647
1990–1999	9356	9251
2000–2008	0	14806
Sum	58542	68473

The relative share of total floor area in need of renovations in 2020 and 2030, all residential buildings.

Building Year	Refurbishment need	
	Share in 2020	Share in 2030
–1920	32%	29%
1921–1939	32%	30%
1940–1959	28%	27%
1960–1969	27%	27%
1970–1979	24%	25%
1980–1989	24%	25%
1990–1999	29%	31%
2000–2008	0%	43%
Average	23%	29%

Renovation needs of residential buildings, light renovations, number of bulidings in need of renovation, 2010–2020.

Building Year	Detached houses	Attached houses	Residential blocks of flats
–1920	18500	200	600
1921–1939	18700	200	900
1940–1959	59100	300	2100
1960–1969	24800	1000	2500
1970–1979	33600	4300	3100
1980–1989	43300	8600	2000
1990–1999	35600	3900	2700
2000–2008	0	0	0
Sum	233600	18500	13900

Renovation needs of residential buildings, light renovations, number of buildings in need of renovation, 2020–2030.

Building Year	Detached houses	Attached houses	Residential blocks of flats
–1920	15900	200	500
1921–1939	15200	100	700
1940–1959	46800	200	1900
1960–1969	20400	900	2400
1970–1979	30500	4000	3000
1980–1989	41200	8200	1900
1990–1999	35300	3800	2700
2000–2008	50100	3900	2300
Sum	255400	21300	15400

Appendix D: Calculation results, energy consumption

This section presents calculation results for energy consumption of the housing stock. These result tables complement those presented in chapter 10.

Energy consumption of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all detached houses, year of concideration is 2020.

	Energy for space heating			Energy for electricity use			Total energy use		
	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %
2020, no energy renovations	29393	0	0	5961	0	0	35354	0	0
Passive-level envelope	25669	3724	13%	5961	0	0%	31630	3724	11%
Ventilation renovation	28693	700	2%	6070	-109	-2%	34763	591	2%
Solar heat installation	29206	187	1%	5968	-7	0%	35174	180	1%
Window renovation	28719	674	2%	5969	-8	0%	34688	666	2%
Renovation combination	24111	5282	18%	6086	-125	-2%	30197	5157	15%

Energy consumption of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all attached houses,, year of concideration is 2020.

	Energy for space heating			Energy for electricity use			Total energy use		
	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %
2020, no energy renovations	5291	0	0	1191	0	0	6482	0	0
Passive-level envelope	4995	296	6%	1191	0	0%	6186	296	5%
Ventilation renovation	5143	148	3%	1208	-17	-1%	6351	131	2%
Solar heat installation	5160	131	2%	1194	-3	0%	6354	128	2%
Window renovation	5163	128	2%	1193	-2	0%	6356	126	2%
Renovation combination	4716	575	11%	1197	-6	-1%	5913	569	9%

Energy consumption of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all residential blocks of flats, year of concideration is 2020.

	Energy for space heating			Energy for electricity use			Total energy use		
	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %
2020, no energy renovations	14116	0	0	2651	0	0	16767	0	0
Passive-level envelope	13375	741	5%	2651	0	0%	16026	741	4%
Ventilation renovation	13272	844	6%	2693	-42	-2%	15965	802	5%
Solar heat installation	13684	432	3%	2651	0	0%	16335	432	3%
Window renovation	13719	397	3%	2654	-3	0%	16373	394	2%
Renovation combination	12306	1810	13%	2697	-46	-2%	15003	1764	11%

Energy consumption of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all residential buildings, year of concideration is 2020.

	Energy for space heating			Energy for electricity use			Total energy use		
	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %
2020, no energy renovations	48800	0	0	9804	0	0	58604	0	0
Passive-level envelope	44039	4761	10%	9803	1	0%	53842	4762	8%
Ventilation renovation	47108	1692	3%	9971	-167	-2%	57079	1525	3%
Solar heat installation	48050	750	2%	9813	-9	0%	57863	741	1%
Window renovation	47601	1199	2%	9816	-12	0%	57417	1187	2%
Renovation combination	41133	7667	16%	9980	-176	-2%	51113	7491	13%

Energy consumption of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all detached houses, year of concideration is 2030.

	Energy for space heating			Energy for electricity use			Total energy use		
	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %
2030, no energy renovations	26388	0	0	5370	0	0	31758	0	0
Passive-level envelope	19127	7261	28%	5370	0	0%	24497	7261	23%
Ventilation renovation	24736	1652	6%	5564	-194	-4%	30300	1458	5%
Solar heat installation	25985	403	2%	5388	-18	0%	31373	385	1%
Window renovation	25006	1382	5%	5391	-21	0%	30397	1361	4%
Renovation combination	15739	10649	40%	5599	-229	-4%	21338	10420	33%

Energy consumption of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all attached houses, year of concideration is 2030.

	Energy for space heating			Energy for electricity use			Total energy use		
	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %
2030, no energy renovations	4829	0	0	1092	0	0	5921	0	0
Passive-level envelope	4235	594	12%	1092	0	0%	5327	594	10%
Ventilation renovation	4545	284	6%	1118	-26	-2%	5663	258	4%
Solar heat installation	4559	270	6%	1096	-4	0%	5655	266	4%
Window renovation	4564	265	5%	1096	-4	0%	5660	261	4%
Renovation combination	3678	1151	24%	1102	-10	-1%	4780	1141	19%

Energy consumption of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for residential blocks of flats, year of concideration is 2030.

	Energy for space heating			Energy for electricity use			Total energy use		
	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %
2030, no energy renovations	12996	0	0	2453	0	0	15449	0	0
Passive-level envelope	11557	1439	11%	2453	0	0%	14010	1439	9%
Ventilation renovation	11291	1705	13%	2530	-77	-3%	13821	1628	11%
Solar heat installation	12116	880	7%	2453	0	0%	14569	880	6%
Window renovation	12176	820	6%	2460	-7	0%	14636	813	5%
Renovation combination	9411	3585	28%	2539	-86	-4%	11950	3499	23%

Energy consumption of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all residential buildings, year of concideration is 2030.

	Energy for space heating			Energy for electricity use			Total energy use		
	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %	Total MWh	Saving MWh	Saving %
2030, no energy renovations	44213	0	0	8915	0	0	53128	0	0
Passive-level envelope	34919	9294	21%	8915	0	0%	43834	9294	17%
Ventilation renovation	40572	3641	8%	9212	-297	-3%	49784	3344	6%
Solar heat installation	42660	1553	4%	8937	-22	0%	51597	1531	3%
Window renovation	41746	2467	6%	8947	-32	0%	50693	2435	5%
Renovation combination	28828	15385	35%	9240	-325	-4%	38068	15060	28%

Appendix E: Calculation results, CO_2-emissions

This section presents calculation results for energy consumption of the housing stock. These result tables complement those presented in chapter 10.

GHG-emissions of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all detached houses, year of concideration is 2020.

	CO2-equ emissions from heating			CO2-equ emis-sions,electricity use			Total CO2-equ emissions		
	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %
2020, no energy renovations	5753	0	0	1337	0	0	7090	0	0
Passive-level envelope	5041	712	12%	1337	0	0%	6378	712	10%
Ventilation renovation	5615	138	2%	1361	-24	-2%	6976	114	2%
Solar heat installation	5714	39	1%	1338	-1	0%	7052	38	1%
Window renovation	5624	129	2%	1338	-1	0%	6962	128	2%
Renovation combination	4735	1018	18%	1365	-28	-2%	6100	990	14%

GHG-emissions of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all attached houses, year of concideration is 2020.

	CO2-equ emissions from heating			CO2-equ emissions,electricity use			Total CO2-equ emissions		
	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %
2020, no energy renovations	1300	0	0	267	0	0	1567	0	0
Passive-level envelope	1226	74	6%	267	0	0%	1493	74	5%
Ventilation renovation	1263	37	3%	271	-4	-1%	1534	33	2%
Solar heat installation	1268	32	2%	268	-1	0%	1536	31	2%
Window renovation	1268	32	2%	268	-1	0%	1536	31	2%
Renovation combination	1158	142	11%	268	-1	0%	1426	141	9%

GHG-emissions of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all residential blocks of flats, year of concideration is 2020.

	CO2-equ emissions from heating			CO2-equ emissions,electricity use			Total CO2-equ emissions		
	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %
2020, no energy renovations	3202	0	0	594	0	0	3796	0	0
Passive-level envelope	3032	170	5%	594	0	0%	3626	170	4%
Ventilation renovation	3009	193	6%	604	-10	-2%	3613	183	5%
Solar heat installation	3104	98	3%	594	0	0%	3698	98	3%
Window renovation	3112	90	3%	595	-1	0%	3707	89	2%
Renovation combination	2788	414	13%	605	-11	-2%	3393	403	11%

GHG-emissions of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all residential buildings, year of concideration is 2020.

	CO2-equ emissions from heating			CO2-equ emissions,electricity use			Total CO2-equ emissions		
	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %
2020, no energy renovations	10255	0	0	2198	0	0	12453	0	0
Passive-level envelope	9299	956	9%	2198	0	0%	11497	956	8%
Ventilation renovation	9887	368	4%	2236	-38	-2%	12123	330	3%
Solar heat installation	10086	169	2%	2200	-2	0%	12286	167	1%
Window renovation	10004	251	2%	2201	-3	0%	12205	248	2%
Renovation combination	8681	1574	15%	2238	-40	-2%	10919	1534	12%

GHG-emissions of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all detached houses, year of concideration is 2030.

	CO2-equ emissions from heating			CO2-equ emissions,electricity use			Total CO2-equ emissions		
	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %
2030, no energy renovations	5169	0	0	1204	0	0	6373	0	0
Passive-level envelope	3771	1398	27%	1204	0	0%	4975	1398	22%
Ventilation renovation	4843	326	6%	1248	-44	-4%	6091	282	4%
Solar heat installation	5085	84	2%	1208	-4	0%	6293	80	1%
Window renovation	4901	268	5%	1209	-5	0%	6110	263	4%
Renovation combination	3101	2068	40%	1255	-51	-4%	4356	2017	32%

GHG-emissions of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all attached houses, year of concideration is 2030.

	CO2-equ emissions from heating			CO2-equ emissions,electricity use			Total CO2-equ emissions		
	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %
2030, no energy renovations	1182	0	0	245	0	0	1427	0	0
Passive-level envelope	1035	147	12%	245	0	0%	1280	147	10%
Ventilation renovation	1111	71	6%	251	-6	-2%	1362	65	5%
Solar heat installation	1116	66	6%	246	-1	0%	1362	65	5%
Window renovation	1116	66	6%	246	-1	0%	1362	65	5%
Renovation combination	900	282	24%	247	-2	-1%	1147	280	20%

GHG-emissions of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildlings in renovation need have been renovated with a certain renovation method. Results are for all residential blocks of flats, year of concideration is 2030.

	CO2-equ emissions from heating			CO2-equ emissions,electricity use			Total CO2-equ emissions		
	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %
2030, no energy renovations	2953	0	0	550	0	0	3503	0	0
Passive-level envelope	2623	330	11%	550	0	0%	3173	330	9%
Ventilation renovation	2565	388	13%	567	-17	-3%	3132	371	11%
Solar heat installation	2754	199	7%	550	0	0%	3304	199	6%
Window renovation	2766	187	6%	552	-2	0%	3318	185	5%
Renovation combination	2133	820	28%	569	-19	-3%	2702	801	23%

GHG-emissions of buildings, a scenario with no renovations compared with scenarios where different energy renovation methods are applied. The results show total energy consumption of the building stock, after all the buildings in renovation need have been renovated with a certain renovation method. Results are for all residential buildings, year of concideration is 2030.

	CO2-equ emissions from heating			CO2-equ emissions,electricity use			Total CO2-equ emissions		
	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %	Total tt	Saving tt	Saving %
2030, no energy renovations	9304	0	0	1999	0	0	11303	0	0
Passive-level envelope	7429	1875	20%	1999	0	0%	9428	1875	17%
Ventilation renovation	8519	785	8%	2066	-67	-3%	10585	718	6%
Solar heat installation	8955	349	4%	2004	-5	0%	10959	344	3%
Window renovation	8783	521	6%	2007	-8	0%	10790	513	5%
Renovation combination	6134	3170	34%	2071	-72	-4%	8205	3098	27%

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Abstract	This report presents the main results of the research project Methods and Concepts for sustainable Renovation (MECOREN) carried out at VTT in 2009–2012. The overall research project was a Nordic collaboration between the following research partners: VTT in Finland, SINTEF in Norway, SBI in Denmark and KTH in Sweden. This report presents methods and concepts for building renovation and analyses the impacts of alternative renovation scenarios on Finnish building stock in terms of energy use and carbon footprint. The focus of the study is on residential buildings. The calculations were carried out for years 2010, 2020 and 2030. In addition to the assessment of the renovation concepts of building stock, the report also – discusses and gives recommendations about the use of environmental data for energy sources – discusses and makes conclusions about the significance of building materials in renovation projects from the view point of greenhouse gases and total energy use – discusses and make recommendations about different renovations concepts – assesses and makes conclusions about the economic impacts of building renovation.
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Name of the project	Mecoren
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Nimeke	**Kestävän korjausrakentamisen menetelmät**
Tekijä(t)	Tarja Häkkinen, Antti Ruuska, Sirje Vares, Sakari Pulakka, Il-po Kouhia, Riikka Holopainen
Tiivistelmä	MECOREN oli pohjoismainen tutkimushanke, jonka tavoitteena oli kehittää konsepteja kestävään korjausrakentamiseen, kehittää menettelytapoja ja ohjeita kestävän korjausrakentamisen arviointiin sekä arvioida rakennuskannan ja rakennusten korjausvaihtoehtojen elinkaarivaikutuksia. Hanke alkoi helmikuussa 2009 ja se päättyi huhtikuussa 2012. VTT koordinoi hanketta; muut tutkimuskumppanit olivat KTH Ruotsista, SINTEF Norjasta ja SBI Tanskasta. Kansallisen hankkeen päärahoittaja oli TEKESin kestävän korjausrakentamisen tutkimusohjelma. Hankkeen muita rahoittajia olivat VTT, Senaatti-kiinteistöt, Helsingin kaupunki, Tampereen kaupunki ja Ilmarinen. Hankkeen tulokset on koottu tähän raporttiin ja hankkeen tulokset ja hankkeen loppuseminaarissa pidetyt esitelmät ovat saatavilla myös MECORENin internet-sivulla osoitteessa http://www.vtt.fi/sites/mecoren/?lang=en Euroopan Unionin kestävän kasvun tavoitteeseen sisältyvät kasvihuonekaasujen vähentäminen 20 %:lla vuoteen 2020 mennessä ja edelleen 20 %:lla vuosikymmenessä siten, että vuoteen 2050 vähennys on peräti 80 % verrattuna vuoden 1990 tasoon. On todettu, että rakennetun ympäristön energiatehokkuuden merkittävä parantaminen ja uusiutuvien energialähteiden hyödyntäminen rakennetun ympäristön käytössä on yksi kustannustehokkaimmista tavoista tavoitteeseen pääsemiseksi.
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