Department of Mechanical Engineering

Low emission energy systems in energy efficient districts

Holistic energy planning, analysis and business opportunities

Mari Hukkalainen (née Sepponen)

Aalto University

DOCTORAL DISSERTATIONS

Aalto University publication series
DOCTORAL DISSERTATIONS 65/2018
VTT SCIENCE 174

Low emission energy systems in energy efficient districts

Holistic energy planning, analysis and business opportunities

Mari Hukkalainen (née Sepponen)

A doctoral dissertation completed for the degree of Doctor of Science (Technology) to be defended, with the permission of the Aalto University School of Engineering, at a public examination held at the lecture hall Otakaari 4, K1, 216 of the school on 20 April 2017 at 12.15.

Aalto University
School of Engineering
Department of Mechanical Engineering

Supervising professors
Professor Risto Lahdelma, Department of Energy Technology, Aalto University School of Engineering, Finland

Thesis advisors
Dr. Miimu Airaksinen, Chief executive officer, Finnish Association of Civil Engineers (RIL), Finland

Prof. Dr. Abdul Samad (Sami) Kazi, Senior Principal Scientist, Research Strategy and Foresight, VTT Technical Research Centre of Finland Ltd., Finland

Preliminary examiners
Lecturer, Dr. Massimiliano Manfren, Sustainable Energy Research Group,
University of Southampton, United Kingdom

Assistant Professor, Dr. Andrew Karvonen, Urban and Regional Studies, KTH Royal Institute of Technology, Sweden

Opponent
Senior University Lecturer, Dr. Minna Sunikka-Blank, Department of Architecture, University of Cambridge

Aalto University publication series
DOCTORAL DISSERTATIONS 65/2018

VTT SCIENCE 174

ISBN 978-952-60-7933-2 (printed)
ISBN 978-952-60-7934-9 (pdf)
ISSN-L 1799-4934
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)
http://urn.fi/URN:ISBN:978-952-60-7934-9

ISBN 978-951-38-8632-5 (printed)
ISBN 978-951-38-8631-8 (pdf)
ISSN-L 2242-119X
ISSN 2242-119X (printed)
ISSN 2242-1203 (pdf)
http://urn.fi/URN:ISBN:978-951-38-8631-8

Unigrafia Oy
Helsinki 2018

Finland

NORDIC ECOLABEL
441 697
Printed matter

Aalto University

Aalto University, P.O. Box 11000, FI-00076 Aalto www.aalto.fi

Abstract

Author
Mari Hukkalainen (née Sepponen)

Name of the doctoral dissertation
Low emission energy systems in energy efficient districts

Publisher School of Engineering

Unit Department of Mechanical Engineering

Series Aalto University publication series DOCTORAL DISSERTATIONS 65/2018

Field of research Community energy technology

Manuscript submitted 19 March 2018 **Date of the defence** 20 April 2018

Permission to publish granted (date) 4 January 2018 **Language** English

☐ **Monograph** ☒ **Article dissertation** ☐ **Essay dissertation**

Abstract

Many climate and energy policy frameworks are leading to stricter energy efficiency and emission regulations and growing share of renewable energy. These will cause changes to the planning and management of energy systems at the local level. Achieving of energy efficient and sustainable districts requires holistic energy planning and optimal energy management. City planners and municipality authorities make many design choices and decisions that significantly impact the energy efficiency and emissions of districts. Energy efficient urban planning can be supported by analysing the energy performance of districts and comparing the environmental impacts of energy system alternatives.

Holistic design and management of district energy systems were studied as a part of sustainable urban planning. The main research themes were 1) district energy analysis, and 2) business concepts for district energy systems and services. The research builds on 14 energy scenario analyses for real life urban planning cases in Finland and abroad. Then, a practical framework and tool was developed for evaluating holistic district energy systems and their environmental impacts in Finland. The tool shows the impacts of urban planning choices on the annual energy demand of a district and compares the carbon emissions of energy supply alternatives. The results can foster and support discussion and raise new ideas for alternative district energy systems.

The near future changes in the foreseen energy transition in cities can make the designing and the management of the district energy systems more complex. Holistic coordination of energy system planning and control are crucial for sustainable district energy systems. New business opportunities are foreseen in the planning and management of local energy systems. District energy services can be arranged in many different ways depending on the needs of the participating actors and the local operation environment. In this research, a set of business concept elements were developed in a form of a cook book. The business concept elements can be modified and combined to create case-specific business models by accounting for local operation environment, conditions and needs.

Keywords energy system, district, analysis, emission, urban planning, business model, smart energy solutions

ISBN (printed) 978-952-60-7933-2 **ISBN (pdf)** 978-952-60-7934-9

ISSN-L 1799-4934 **ISSN (printed)** 1799-4934 **ISSN (pdf)** 1799-4942

Location of publisher Helsinki **Location of printing** Helsinki **Year** 2018

Pages 182 **urn** http://urn.fi/URN:ISBN:978-952-60-7934-9

A! Aalto-yliopisto

Tiivistelmä

Aalto-yliopisto, PL 11000, 00076 Aalto www.aalto.fi

Tekijä
Mari Hukkalainen (née Sepponen)

Väitöskirjan nimi
Vähäpäästöiset energiajärjestelmät energiatehokkailla alueilla Kokonaisvaltainen energiasuunnittelu, -analyysi ja liiketoimintamahdollisuudet

Julkaisija Insinööritieteiden korkeakoulu

Yksikkö Konetekniikan laitos

Sarja Aalto University publication series DOCTORAL DISSERTATIONS 65/2018

Tutkimusala Yhdyskuntien energiatekniikka

Käsikirjoituksen pvm 19.03.2018 **Väitöspäivä** 20.04.2018

Julkaisuluvan myöntämispäivä 04.01.2018 **Kieli** Englanti

☐ **Monografia** ☒ **Artikkeliväitöskirja** ☐ **Esseeväitöskirja**

Tiivistelmä

Monet energia- ja ympäristötavoitteet ohjaavat parantamaan energiatehokkuutta, vähentämään päästöjä ja lisäämään uusiutuvan energian osuutta. Näistä aiheutuu muutoksia aluetason energiajärjestelmien suunnitteluun, hallintaan ja ohjaukseen. Energiatehokkaiden ja kestävän kehityksen mukaisten alueiden toteuttaminen vaatii kokonaisvaltaista energiasuunnittelua ja optimaalista energiajärjestelmän hallintaa. Aluesuunnittelijat ja kunnalliset päätöksentekijät tekevät monia suunnitteluvalintoja ja päätöksiä, jotka vaikuttavat alueiden energiatehokkuuteen ja päästöihin merkittävästi. Energiatehokasta aluesuunnittelua voidaan tukea tarkastelemalla alueen energian käyttöä ja vertailemalla energiajärjestelmävaihtoehtojen ympäristövaikutuksia.

Tässä väitöskirjassa tutkittiin alueiden energiajärjestelmien kokonaisvaltaista suunnittelua ja hallintaa osana kestävää aluesuunnittelua. Tutkimuksen pääteemoina olivat 1) alueiden energiatarkastelu, ja 2) liiketoimintakonseptit alue-energiajärjestelmille ja -palveluille. Tutkimus pohjautuu 14 todellisen aluesuunnitelman energiatarkastelulle. Tutkimuksessa kehitettiin käytännönläheinen lähestymistapa ja työkalu, jolla voidaan arvioida kokonaisvaltaisesti alue-energiajärjestelmiä ja niiden ympäristövaikutuksia Suomessa. Kehitetyllä Kurke-työkalulla voidaan näyttää, miten aluesuunnittelun valinnat vaikuttavat alueen vuotuiseen energiantarpeeseen, ja vertailla eri energiantuotantovaihtoehtojen kasvihuonekaasupäästöjä. Tarkastelun tulokset voivat tukea keskustelua ja tuoda uusia vaihtoehtoja alueiden energiajärjestelmiin ja niihin liittyviin suunnitteluvalintoihin.

Lähitulevaisuudessa energiajärjestelmissä tapahtuu muutoksia, jotka voivat tehdä alue-energiajärjestelmien suunnittelusta ja ohjauksesta monimutkaisempaa. Optimaalinen energiahallinta ja kokonaisvaltainen energiajärjestelmän suunnittelun ja käytön koordinointi ovat avainasemassa, kun tavoitellaan kestäviä alue-energiajärjestelmiä. Paikallisten energiajärjestelmien suunnittelusta ja hallinnasta voi syntyä myös uusia liiketoimintamahdollisuuksia. Aluetason energiapalveluja voidaan järjestää monilla eri tavoilla, riippuen osapuolien tarpeista ja paikallisista lähtökohdista. Tässä tutkimuksessa kehitettiin kokoelma liiketoimintakonsepteja ja osakonsepteja, jotka on esitetty alue-energiapalveluiden "keittokirjana". Näitä konsepteja ja elementtejä yhdistelemällä voidaan kehittää paikalliseen toimintaympäristöön, olosuhteisiin ja tarpeisiin sovitettuja liiketoimintamalleja alue-energiapalveluille.

Avainsanat energiajärjestelmä, alue, analyysi, päästöt, aluesuunnittelu, liiketoimintamalli, älykkäät energiaratkaisut

ISBN (painettu) 978-952-60-7933-2 **ISBN (pdf)** 978-952-60-7934-9

ISSN-L 1799-4934 **ISSN (painettu)** 1799-4934 **ISSN (pdf)** 1799-4942

Julkaisupaikka Helsinki **Painopaikka** Helsinki **Vuosi** 2018

Sivumäärä 182 **urn** http://urn.fi/URN:ISBN:978-952-60-7934-9

Preface

Some years ago I was enjoying my second real, long summer vacation since childhood. One day I went to jogging and enjoying the nature by the seaside of Helsinki, when the idea and aspiration for making a PhD hit on for the very first time. Half a year later, I started as a part-time PhD student at Aalto University School of Engineering. There was a newly set program for Energy Technology for Communities, focusing on a topic that had fascinated me many years already. My PhD studies were guided by professor Risto Lahdelma, who I would like to thank for all the support throughout my studies and enabling me to fit the PhD work together with my research work at VTT.

My work as a senior scientist at VTT Technical Research Centre of Finland Ltd. supported my PhD studies very well. Truly speaking, I wouldn't be writing this without the ambition, learnings and experiences I have gotten from VTT. I have met interesting people with differing backgrounds, and learned a lot from them. I would like to thank all of them, and especially the following project partners and funders for collaboration. Ekotaajama was funded by Sitra and TEKES and the municipalities of Jyväskylä, Multia, Jämsä, Kannonkoski, Toivakka, and Petäjävesi. EcoDrive was funded by TEKES and ARA, in collaboration with Aalto university and University of Helsinki and the cities of Tampere, Kankaanpää, Helsinki, Kokkola and Riihimäki. EcoGrad and Modern-Moscow were funded by the Ministry for Foreign Affairs of Finland. TEKES funded Kurke (Kunnallisen rakentamisen kestävät ratkaisut) offered a possibility to develop a methodology and a tool for assessing the energy efficiency and carbon emissions of urban plans. Various EU-funded project brought further understanding about the situation in Europe, e.g. business concepts of EnergyHUB, and the future research roadmaps for ICT for energy and cities in IREEN and Ready4SmartCities. Thanks to VTT also from supporting me to write the summary of this thesis.

Mostly, my motivation has still been enhanced by my colleagues at VTT. I would like to thank Miimu Airaksinen for energetic support and ideas, and my team leader Jari Shemeikka and our research area manager Tuula Mäkinen for being there always when needed. I would also like to thank all my colleagues. Especially, I thank for Satu, Mikko, Ha, Mia, Åsa, Ismo, Rinat, Riikka, Kalevi and Maija, I have enjoyed working with you! Special thanks to Matti and Isabel, I enjoy working with you and have learned a lot from you, both about work and life! Thanks to Sami Kazi for the encouragement and a bit of push to bring this journey to end!

Thanks for my dear family and friends for the support and time spent together. You bring joy to my life. Big hugs to my parents Tuula and Timo, and to my siblings Salla-Maarit and Mikko and their families, you are beloved to me! And most importantly, I thank my husband Hukka, for sharing the ups and downs, and for everything that you are and have done for me. Our son Aleksi is the best company ever, bringing happiness to us (and making sure I don't work too much!). Now, I'm looking forward our soon further growing family and all the new things what that will bring for us! Love you!

18th of December 2017, Espoo
Mari Hukkalainen

List of publications

This thesis is based on the following original publications which are referred to in the text as Papers I–VII (Appendixes A – E). The publications are reproduced with kind permission from the publishers.

I Paiho Satu, Hedman Åsa, Abdurafikov Rinat, Hoang Ha, **Sepponen Mari**, Kouhia Ilpo, Meinander Malin. 2013. Energy saving potentials of Moscow apartment buildings in residential districts. Energy and Buildings vol. 66, 2013, p. 706 – 713. Elsevier. http://dx.doi.org/10.1016/j.enbuild.2013.07.084

II Paiho Satu, Hoang Ha, Hedman Åsa, Abdurafikov Rinat, **Sepponen, Mari,** Meinander Malin. Energy and emission analyses of renovation scenarios of a Moscow residential district. Energy and Buildings vol. 76, June 2014, p. 402 – 413. Elsevier. http://dx.doi.org/10.1016/j.enbuild.2014.03.014

III Hedman Åsa, **Sepponen Mari**, Virtanen Mikko. Energy efficiency rating of districts, case Finland. Energy Policy, vol. 65, February 2014, p. 408 – 418. Elsevier. doi:10.1016/j.enpol.2013.10.022

IV **Sepponen Mari**, Heimonen Ismo. Business concepts for districts' Energy hub systems with maximised share of renewable energy. Energy and Buildings, vol. 124, 15 July 2016, p. 273 – 280. Elsevier. http://dx.doi.org/10.1016/j.enbuild.2015.07.066

V **Hukkalainen Mari,** Virtanen Mikko, Paiho Satu, Airaksinen Miimu. Energy planning of low carbon urban areas - Examples from Finland. Sustainable Cities and Society, vol. 35, November 2017, p. 715 – 728. Elsevier. https://doi.org/10.1016/j.scs.2017.09.018

Author's contributions

The author's main contributions in Papers I–III and V focused on the energy and emission analysis for case districts, including the selection of studied cases and choice of the methods, as well as the scenario development, base data collection, analysis and interpretation of the results. All papers were team efforts and developed in collaboration among the research project team members.

In Paper I [Paiho et al., 2013], the author defined energy analysis methods used and led the performing of the energy analyses. The author had the main responsibility in defining the alternative building renovation concepts. She also contributed to the literature review, choice of the case study area, and the discussion and conclusions. Paiho was first author with main responsibility and she lead the paper writing. Hedman contributed to the development of renovation scenarios and to chapters 6 and 7. Abdurafikov assured that the study captured the Russian special characteristics. Hoang developed figure 3. Kouhia provided practical expertise and guidance as the basis for the energy analysis. Meinander assessed the water solutions.

In Paper II [Paiho et al., 2014], the author was responsible for describing the methodology for energy chain analysis, defining energy efficient building renovation concepts, and the assessing the life cycle emissions. The author defined energy supply scenarios studied, and participated in scenario analyses and comparisons in collaboration with Hoang. She also contributed to the introduction, literature review, and conclusions and discussion related to energy and emission analysis. Paiho lead the research work and the paper writing. Hedman contributed to the scenario development and paper writing. Abdurafikov assured the application of Russian characteristics. Meinander studied water solutions.

In Paper III [Hedman, Sepponen, and Sepponen 2014], the author collected the base data, performed the energy analysis for the case areas and contributed to discussion and conclusions. The author contributed to the background, literature review, and to the description of the developed tool and its relation to Finnish energy use and supply and related policies. Hedman led the research work. Virtanen developed the excel tool, and participated to energy analysis in collaboration with the author.

The author had the main responsibility of the Paper IV [Sepponen and Heimonen, 2016]. Heimonen provided expertise and support on business models and barriers.

In Paper V [Hukkalainen et al., 2017], the author led the paper development. Virtanen contributed to the analysis of passenger transport, areal efficiency, and to the development of the Kurke tool in collaboration with the author. Paiho supported structuring the paper and its literature review and discussion. Airaksinen contributed to discussion, conclusions and visualising and highlighting the analysis results.

Contents

Appendices

List of symbols and abbreviations

BAU	Business as usual
CHP	Combined heat and power generation
COP	Coefficient of performance
CO_2	Carbon dioxide
EC	European Commission
EE	Energy efficient
EPBD	Energy Performance of Buildings Directive
EU	European Union
GWP	Global warming potential
HVAC	Heating, ventilation and air conditioning
ICT	Information and communication technology
IoT	Internet of things
KPI	Key performance indicator
LCA	Life cycle assessment
NEMS	Neighbourhood Energy Management Systems
RES	Renewable energy sources
SO_2	Sulphur dioxide
TOPP	Tropospheric ozone precursor potential

1. Introduction

1.1 Motivation

The need to mitigate climate change has put pressure for international cooperation in tandem with local, national, and regional policies on many distinct matters [IPCC, 2014]. The European Commission (EC) has reacted to the mitigation need by setting climate policy targets for the year 2020 as so-called 20-20-20 targets so as to reduce greenhouse gas emissions by 20%, raising the share of renewable energy sources use by 20% and improving energy efficiency by 20% [European Parliament and Council, 2008]. In 2014, the EC updated the climate policy targets in an integrated policy framework towards a low-carbon economy for the period up to 2030 [EC, 2014a]. The 2030 framework [EC, 2014a] aims to reduce EU domestic greenhouse gas emissions by 40% below the 1990 level by 2030, and hence, to ensure the cost effective path towards cutting carbon emissions by at least 80% by 2050. It also aims to increase the share of renewable energy to at least 27% of the EU's energy consumption by 2030, and increase energy savings by 30% for 2030 [EC, 2014a]. The climate policy targets have been distributed among the Member countries according to their relative wealth [EC, 2014b].

As a consequence, Finland has set long-term climate and energy strategy targeting to 2020 [Government of Finland, 2008] and beyond towards 2050 [Government of Finland, 2009]. This strategy mainly seeks to cut Finland's carbon emissions by 80% from the 1990 level by the year 2050, which requires the adaptation of energy and transport systems to nearly zero emission level and an increase in the use of renewable energy. It also strives to improve energy efficiency, including stricter building standards leading towards the zero energy buildings. Energy system goals also include better balance between energy use and supply, and development towards a zero-emission energy system with a gradual reduction of carbon emissions [Government of Finland, 2009]. The strategy [Government of Finland, 2009] also states that ICT can support emission reductions, and its utilisation potential and the required means need to be explored. The Finnish climate and energy strategy was updated in 2013 [Government of Finland, 2013], and it envisaged that Finnish urban regions could be forerunners in the development of low-carbon communities though realising bold goals and experiments.

The local government sectors have already introduced many energy- and climate-related cooperation agreements and schemes both in Finland [Motiva, 2015; Hinku, 2015] and internationally [Covenant of Mayors, 2015; Sperling et al., 2011; Brandoni and Polonara, 2012]. Over 40% of Finnish municipalities are engaged to systematic climate efforts, and some third of them have a climate strategy [Government of Finland, 2013]. For example, the City of Tampere aims to reduce its CO_2 emissions by 40% by 2025 [Tampere, 2013], Helsinki aims to reduce carbon emissions 30% by 2020 [Helsinki, 2013], and Porvoo has decided to invest in eco efficient urban planning and favours renewable energy sources [Porvoo, 2010]. Some examples of sustainability targets set by European cities include, for instance, the City of Stockholm (Sweden), which aims to be fossil fuel-free by 2050, and Copenhagen (Denmark), which seeks to be carbon-neutral by 2025 [Kramers et al., 2013]. Also Malmö (Sweden), Freiburg (Germany) and Hamburg (Germany) are seeking to reduce their CO_2 emissions by 40% by 2020 [Kramers et al., 2013].

When one begins to realise the climate and energy targets, commitment is needed from many levels: the international [EC, 2014b], and national, regional and local city level [Neves and Leal, 2010]. The city authorities and local energy utilities play a key role in reducing local carbon emissions through decision making, planning and management of actions in the short, medium and long term, including among others land use, energy supply and transport planning [Neves and Leal, 2010]. The Finnish climate and energy strategy encourages municipalities to plan energy efficient, high-quality communities, and it states that planning and assessment tools employed to this end are needed, as well as coherence of emissions calculations in regional climate efforts and supporting tools for municipalities and municipal residents in making energy- and material-efficient choices [Government of Finland, 2013]. Similarly, among others Azevedo et al. [2013] have recognised the significant role of city authorities in the organising the energy supply and demand in cities and the need for a methodology for the evaluation of cities' energy and climate performance e.g. based on local energy consumption and CO_2 emissions. This dissertation contributes to these recognised needs.

1.2 Research problem

The overall aim of this dissertation is to provide the means for improving the sustainability and energy efficiency of districts. Districts are considered as an optimal scale for combining energy efficiency activities with promising energy strategies implementation [e.g. Marigue and Reiter., 2014; Neves and Leal, 2010; Mohareb and Kennedy, 2014], for example with the advanced and efficient utilisation of local renewable energy sources [Manfren et al., 2011; Bhatt et al., 2010].

This dissertation studies holistic energy planning and its' impacts on the overall energy efficiency of districts. The research builds on many energy scenario analyses for real life urban planning cases in Finland and abroad.

The main research problem is: What makes districts energy efficient and low carbon? How much and by which means can districts' energy efficiency and sustainability be improved?

- How could district energy and emission analysis support designing more sustainable and energy efficient districts? How to make it fast and practical to use, but still keep the appropriate level of detail?
- How to organise new district energy business concepts with hybrid energy sources?

The research expectation is that the assessment of district's energy performance and its environmental impacts would support improving urban plans through identifying the best possible opportunities for developing a high-quality, sustainable and comfortable urban area with high energy performance. This expectation is supported by recent research findings that those energy systems that are planned and managed with holistic coordination have higher energy efficiency, and their emissions can be reduced more significantly [e.g. Yamagata and Seya, 2013; Mirakyan and De Guio, 2013; Sperling et al., 2011; Bhatt et al., 2010].

1.3 Scope of the research

This dissertation focuses on energy efficiency of districts, including the entire energy chain from energy supply to distribution and demand in urban areas. On the energy demand side, the focus is primarily on buildings, including residential, service and office buildings. Some case studies also include the energy demand of waste and water management. Energy demand of passenger transportation is included in some cases. Consumption of goods is excluded from the study. Regarding energy supply, the main focus is on the local scale solutions, e.g. district heating and local and on-site energy production systems. The interconnections to broader energy systems are considered, e.g. to national electricity system. Figure 1 illustrates the research scope focusing on the energy systems of districts.

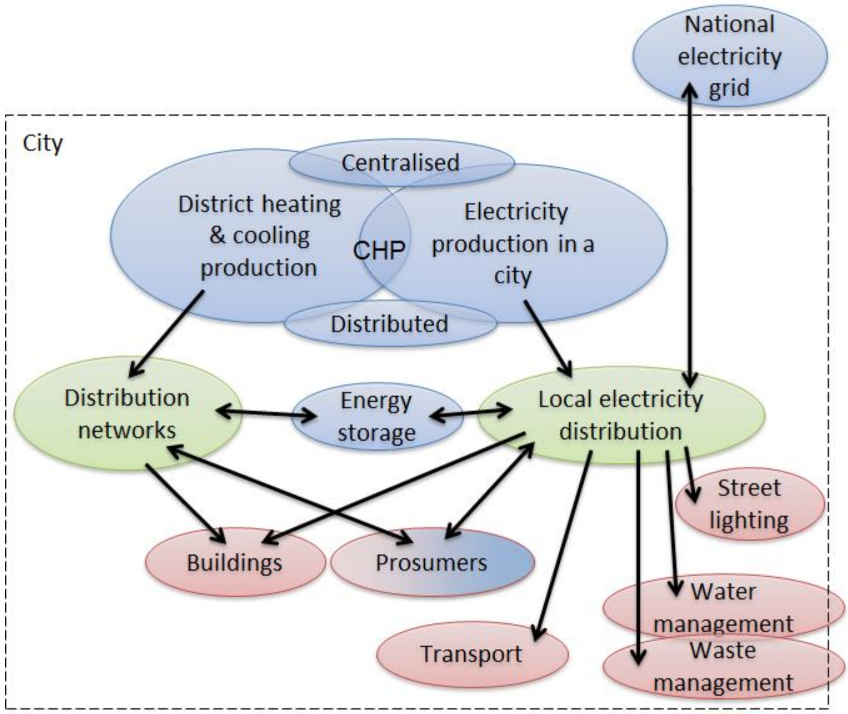


Figure 1. The scope of the study, including energy production (blue), distribution (green) and demand (red) in urban areas.

1.4 Outline of the dissertation

The literature review in Section 2 describes the factors affecting to the energy efficiency and sustainability of districts, and the potential means for improving it. The used research approaches and methods are summarised in Section 3.

According to the research questions, this dissertation focuses on analyses and business models for district energy systems. Firstly, district energy and emission analyses of 14 real life case studies are summarised in Section 4, describing the energy performance and supply scenarios. These results provide the foundations for developing a framework and tool for district energy analysis supporting urban planning, as presented in Section 5. Secondly, the new business opportunities for energy service and management are identified based on stakeholders' requirements in Section 6. Concluding lessons and recommendations for energy efficient districts and their energy systems are given in Section 7.

2. Literature review of energy efficient districts and their energy systems

This dissertation studied how to achieve a holistically designed and operated district energy system, and how it can be part of sustainable urban planning. Here it is crucial to take into account the entire energy chain [Kılkış, 2014]. The key elements for the integrated planning and operation of district energy systems are presented in Figure 2. Previous research has addressed these elements from different viewpoints as summarised in following chapters. At the end of the literature review, the state of the art and related research gaps are summarised (in Section 2.7 in Table 1).

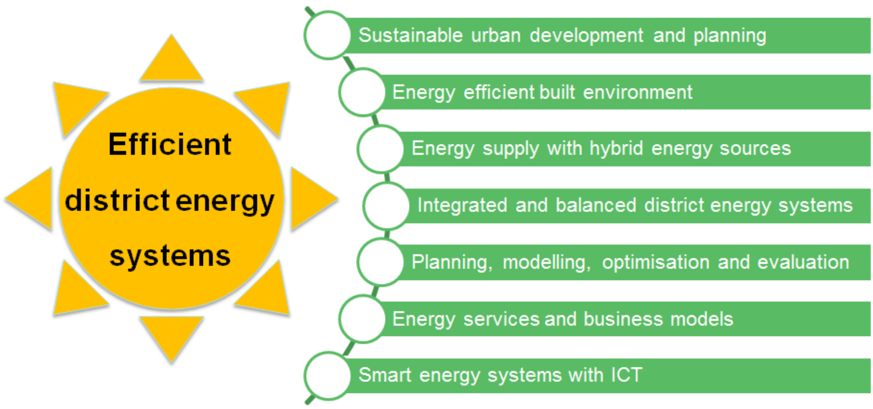


Figure 2. The key elements of efficient district energy systems

Marigue and Reiter [2014] proposed the following targets for local communities when aiming to improve their sustainability: 1) improve energy efficiency of the building stock, 2) minimise the energy demand of buildings and transportation through occupant behaviour, 3) maximise the on-site renewable energy production, and 4) use off-site renewable energy production. Similar principle is used in this research.

2.1 Sustainable urban development

"*Sustainability is a continuous process of balancing the environmental, economic and social aspects related to the living environment and their systematic improvements*" [Rad, 2010].

Large urban regions have a central position in both causing and mitigating climate change, and hence they need to bear their share of the global responsibility, while ensuring vitality, well-being and sustainability in the long term [Government of Finland, 2013]. Hassan and Lee [2015] studied the recent trends in the context of sustainable urban development, and identified the following most relevant topics: (1) A balanced approach to sustainable urban development (from the viewpoints of environment, economy and social issues), (2) Socio-cultural awareness, (3) Urban sprawl, (4) Economic urban development, (5) Transportation, (6) Urban renewal, (7) Mitigating greenhouse gases (GHG), (8) Urban vegetation, (9) Assessment systems, and (10) City structure and land use.

The Finnish climate and energy strategy [Government of Finland, 2013] states that the development of urban areas should now focus on cohesive urban structure through land use planning and construction management so as to create a high-quality living environment. The sufficient population base in built-up areas is needed to ensure the economic municipal infrastructure, public transport and the availability and access to services. The development of land use, housing and transportation should support walking, cycling and public transport and to reduce the dependence on private cars. One of the keys here is to focus the housing construction in areas near efficient public transport connections. [Government of Finland, 2013]

Sustainable and ecological urban developments have been studied in Finland among others by Lahti et al. [2008], and many Finnish pilot cases exists, e.g. in Eco Viikki district in Helsinki [Hakaste et al., 2005], and in the Vuores area in the City of Tampere [Paiho et al., 2013]. The Finnish city planning process is described in Paper III [Hedman, Sepponen and Virtanen, 2014].

2.1.1 Sustainable urban planning

The spatial planning and land use policies can be a viable instrument in mitigating and adapting to the climate change issues, if they are implemented effectively [Kumar and Geneletti, 2015]. Municipal authorities play a key role in affecting local greenhouse gas emissions through decision making and various development actions, including urban and transport planning, and used energy sources [Neves and Leal, 2010]. For example, municipalities can promote the use of renewable energy through urban plans and building permits. Energy efficiency can be increased by raising the awareness of residents and guiding stakeholders on how to improve a city’s infrastructure, systems, and building performance. [Monni and Syri, 2011; Mickwitz et al., 2011]

The significance of urban area density for sustainability has recently been discussed a great deal in Finland and internationally. Heinonen [2012] claimed that “the urban structure has a direct impact only on the emissions related to private driving, whereas the emissions from other consumption activities closely follow the overall consumption”. Heinonen [2012] argues that “while the environmental, social and functional importance of high urban density and the building type have been demonstrated in a number of studies, from the climate change perspective these factors are not decisive and they are not sufficient measures for effective city level carbon management”. However, for example Yamagata and Seya [2013] indicated that compact (/dense) urban areas may reduce the electricity demand from the residential sector compared to a dispersed urban area, but on the other hand dispersed areas with detached houses have more potential for solar electricity supply due to a greater availability of suitable photovoltaic panel installation area in respect of the total building floor area. Also Bhatt et al. [2010] stated that emissions can be influenced through changes in land use patterns, which affect living, working, and transportation patterns.

Many significant decisions at the very beginning of the planning process have effects on the energy system of the district. Some examples of these decisions include the location of services, links to the existing (regional) urban infrastructure, size and the form of transportation networks, and accessibility to jobs and services. Urban planners' other decision points are related to defining the land use and layout of the area, the scale and type of buildings, as well as specifications of transportation and other urban networks. [Yeo et al., 2013]

Mohareb and Kennedy [2014] state that there is no clear or simple strategy that could be applied universally for cities on the pathway to a low-carbon future, but instead cities need to identify suitable strategies within their individual context, and that those actions should be swift and aggressive in their approach so as to achieve the planned significant low carbon reduction targets by 2050. Localisation is also crucial for the assessments of urban areas [Haapio, 2012].

2.1.2 Links between urban planning and energy systems

Zaron and Verones [2012] stated that urban and spatial planning and the energy system planning should be closely linked together early on the urban planning process, since the energy consumption and potential local energy sources are strongly connected to the urban plans. Eicker et al. [2015] also recognised that cities have difficulties in effectively evaluating the most suitable urban energy planning concepts, and they proposed a methodology for evaluating building energy performance and PV potential in Munich, Germany. They concluded that the achievement of zero energy balances often requires combining the energy efficient buildings and their PV supply with other, more centralised renewable resources such as deep geothermal, solar or biomass heat or cogeneration plants.

When local communities are realising the sustainable energy initiatives related to increasing decentralised sustainable energy supply, development of a shared vision and concrete goals is an important starting point [van der Schoor and Scholtens, 2015]. The further development of organisation structures and viable visions for local energy governance are required to achieve long-term results [van der Schoor and Scholtens, 2015].

2.2 Toward a highly energy efficient built environment

The energy efficiency of buildings has been studied already for a long time starting in the 1950s, and many supportive active and passive technologies and solutions have been developed since. However, due to the long life cycle of the building stock, the changes are slow. Some of the recent Finnish research activities in the field have been summarised e.g. in Airaksinen [2012]. One of the long term performance examples of energy efficient buildings with on-site renewable energy production in Finland is the so-called IEA5-building built in Pietarsaari in 1994 [Thomsen et al., 2005]. This singly family building and especially its solar energy supply system has been performing as planned for 20 years now, and it still fulfils the requirements for EC's nearly zero energy building in EBPD [Thomsen et al., 2005].

Due to the need to reduce buildings' energy demands, the EC adopted the Energy Performance of Buildings directive (EPBD) in 2010 [EC, 2010/31] for adopting highly efficient nearly zero energy building performance requirements for both new and existing buildings. The directive requires that by 2021 all new buildings are so-called 'nearly zero energy buildings', and public sector buildings already by 2018. As a consequence, the directive guides towards an increase in on-site distributed energy production. Zero energy buildings are already piloted also in Finland, e.g. a zero energy apartment building for the elderly in Järvenpää was built in 2011 and a zero energy building for student housing in 2010 in Kuopio [Järvenpään mestari-asunnot, 2011]. Also, nearly zero energy buildings are piloted, as for example an elderly home in Lahti (constructed 2011-2014) [Nieminen, 2011].

According to Marszal et al. [2011], the most frequently used definition for zero energy buildings is that their annual energy balance is zero, in other words they have annually as much energy production as they are demanding. The detailed definition work for a nearly zero energy building is still on-going in Finland and Europe, but in general the aim is to maximise buildings' efficient energy utilisation, and on the other hand to produce some amount of the energy required on-site or in the vicinity of the building. However, it is not yet clear how the vicinity is actually defined. In 2012, the EPBD was supplemented with a regulation about setting up a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements [EC, 2012]. The goal is that the nearly zero energy buildings would be defined and designed by their optimum cost efficiency level of total costs for investment and operation.

In the longer term, zero energy buildings are seen an integral part of a future smart city contributing among others to an increased share of renewable energy sources use and intelligent energy management as an active part of a smart grid and the city's energy system [Kyliki and Fokaides, 2015]. Recently, the research focus has also been broadening from zero energy buildings to zero energy neighbourhoods and districts, as can be seen e.g. from Ala-Juusela et al. [2014] and Marigue et al. [2014].

2.3 Paradigm shift from centralised to hybrid energy supply

Traditionally, most of the electricity and heat supply is based on centralised energy supply plants [Sampaio et al., 2013]. Energy markets are dominated by a few large energy providers and they often use long-term energy contracts. It has been straightforward, and big production units do have higher process efficiency than for smaller and distributed production units. Typically, most of the energy sources used are mainly fossil fuels, as can be seen in Figure 3 for Finnish electricity supply.

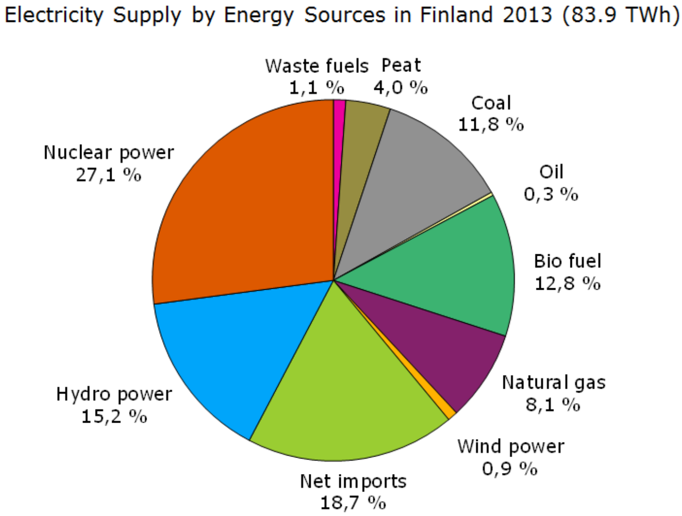


Figure 3. Energy sources of electricity supply in Finland in 2013 [Finnish Energy industries, 2014a].

The energy sources used buildings' space heating is shown in Figure 4 and the fuel use of district heating and CHP in Finland in Figure 5. District heating is widely used in Finland, and 74% of it is produced with CHP, and the remainder in separate district heating utilities [Finnish Energy Industries, 2014b]. However, the traditional energy supply is acquiring new alternatives in the near future.

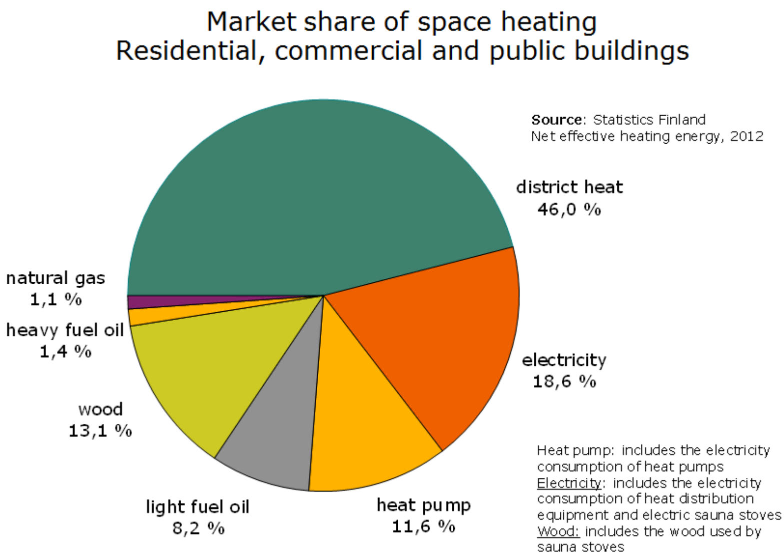


Figure 4. Market share of space heating in residential, commercial and public buildings in Finland [Energy industries, 2014b].

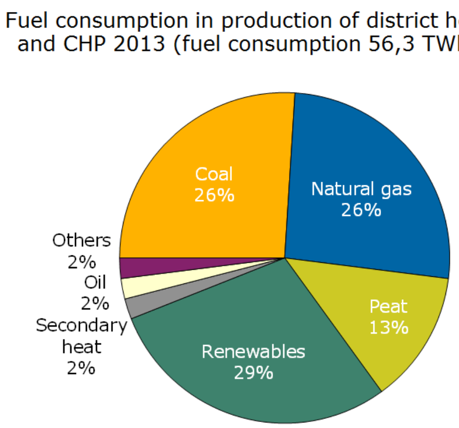


Figure 5. Fuel consumption in production of district heat and CHP in 2013 [Finnish Energy Industries, 2014b].

A paradigm shift is expected from centralised energy supply and one-way energy distribution to hybrid energy source supply with an increase in the share of distributed energy supply from buildings and districts [Manfren et al., 2011]. This development is also strongly supported and driven by the expected decreasing of investment costs of renewable energy production systems such as solar photovoltaic panels [IEA, 2014; Baker et al., 2015]. Manfren et al. [2011] state “that the energy system transition comprises a very high level of complexity at both local and global scale” and it is very hard to predict the real effects of measures and actions, and that there still exists “barriers at the infrastructural, economic, regulatory, political and administrative level”.

Overall, local and renewable energy production systems in districts can be implemented at different levels: as a part of the city’s system, or as a district level system, or in smaller units in blocks of buildings or even separately in individual buildings [Nystedt et al., 2012]. Solar collectors and their integration into district heating with thermal energy storage applications have been studied by e.g. Flynn and Sirén [2015], Carpaneto et al. [2015] and Paiho et al. [2015]. Different kinds of heat pump integrations into the district heating systems have been studied from different viewpoints [e.g. Soltani et al., 2015, Alavy et al., 2014].

2.4 Integrated approach to district energy systems

The realisation of cities’ low emission and sustainability targets requires an integrated approach targeting significant improvements in the overall energy efficiency of urban areas through efficient land use planning, sustainable energy systems and transportation [Yamagata and Seya, 2013], but without compromising the comfortable living environment for citizens [Government of Finland, 2013]. Bhatt et al. [2010] state that municipal energy systems need to be considered as a whole, including possible interactions and interdependencies among the system components. This will ensure having a comprehensive view of the overall complex energy system and its long-term performance with respect to different assumptions and influences [Bhatt et al., 2010].

Manfren et al. [2011] conclude that, in the transition to more efficient energy systems, key elements that have to be taken into account are: “the optimal matching of energy supply and demand, the optimal mix of uses in the built environment (for balancing different energy demands and loads) the use of energy cascades and polygeneration systems and, of course, the peculiarities related to local available energy, economic and environmental resources”.

According to Zinck Thellufsen and Lund [2015], system effects and possible synergies of various energy savings can be identified through analysing the entire energy system. For this, they propose the following approach: identifying energy sectors with possible interconnections; creating scenarios analysing the interconnections; and analysing the scenarios to identify the synergy possibilities. As a result, coordination possibilities for the saving initiatives and the energy system can be identified so as to achieve the synergy benefits between them [Zinck Thellufsen and Lund [2015].

2.4.1 Integrated energy planning

The importance of integrated urban energy planning has been recognised e.g. by Mirakyan and De Guio [2013], Sperling et al. [2011] and Bhatt et al. [2010]. Mirakyan and De Guio [2013] defined the integrated long-term, model-based energy planning as “Regional (sub-national) integrated energy planning is an approach to find environmentally friendly, institutionally sound, social acceptable and cost-effective solutions of the best mix of energy supply and demand options for a defined area to support long-term regional sustainable development. It is a transparent and participatory planning process, an opportunity for planners to present complex, uncertain issues in structured, holistic and transparent way, for interested parties to review, understand and support the planning decisions”.

Mirakyan and De Guio [2013] have presented a generic integrated energy planning procedure with four main phases. The phases suggested for the planning procedure reflects the decision-making process and the working phases: 1) Preparation and orientations, 2) Model design and detailed analysis, 3) Prioritization and decision, and 4) Implementation and monitoring. These phases and steps are interlinked, and they are therefore not necessarily performed in a predetermined sequence, but rather as step iterations [Mirakyan and De Guio, 2013].

According to Bhatt et al. [2010], traditionally every subsystem of an urban energy system is studied and planned individually, and is eventually combined into an overall energy plan. Typically, this leads to a suboptimal system, because the various interdependencies between energy system components are ignored [Bhatt et al., 2010]. Energy systems would greatly benefit from a systemic approach and long-term strategic planning due to the following characteristics [Bhatt et al., 2010]:

- Many different actors are carrying out the planning and operation of energy systems, with the possibility of conflicting goals. Also, other local stakeholders may have different opinions about the optimal energy supply system.
- Changes and responses in the energy systems often take a long time, because they consist of long-lasting infrastructures (with life-times up to 50 years). For this reason, it is important to consider long-term developments in relation to the current and future framework conditions, such as energy prices, economic growth, socioeconomic changes etc.
- The energy system includes many interdependent subsystems, and changes in a subsystem can affect to the other subsystems. There are many different options for energy supply technologies to fulfil the energy demands and services.
- Energy efficiency-related changes in the demand side can compete with the measures on the energy supply side. As both capital and human resources are scarce, the overall energy efficiency improvements should be directed to the most effective measures.
- The profitability of the investments must be evaluated in the context of uncertain socioeconomic issues (e.g. general economic development, energy prices, taxes and legislation).

- The energy system planning interacts with strategic planning in other fields. For example, urban and land use planning, environmental planning or transportation planning affects the energy system.
- Changes in the energy system have large impact to the urban environment, through the impacts to residents, local industries, and the environment.

Bhatt et al. [2010] also argue that investments in local renewable energy sources (biomass, wind, solar energy, hydroenergy, waste heat, etc.) are often expensive and need a stable, long-term demand and commitment to justify the investment. However, currently the situation is changing, as the distributed renewable energy production systems are declining [IEA, 2014; Baker et al., 2015]. Local conditions affect to the profitability of the systems significantly, as e.g. district heating production from biomass has been very competitive choice in Finland for a long time already.

Numerous tools and models are already available for communities' energy planning [Prasad et al., 2014; Huang et al., 2015]. Nevertheless, planners would still benefit from new systematic and effective assessment indicators and methods for analysing the community energy systems, when they are setting energy consumption goals and putting forward energy efficient proposals [Huang et al., 2015].

2.4.2 Energy system modelling and optimisation

The paradigm shift increases the need for optimal energy planning and modelling in using and selecting a mix of hybrid energy sources. Early decentralized energy planning models and applications were reviewed by Hiremath et al. [2007]. Optimisation and modelling techniques for renewable electricity systems have been broadly reviewed by Bazmi and Zahedi [2011]. More recently, Mirakyan and De Guio [2013] have reviewed methods and tools for diverse planning tasks mapped to a generic integrated energy planning procedure. They conclude that the methods and the tools have not yet been combined to manage all of the integrated energy planning processes and tasks, and in particular supporting planning tools are lacking from the first planning phase (preparation and orientation) [Mirakyan and De Guio, 2013]. Also e.g. Mendes et al. [2011] have reviewed a number of energy bottom-up tools for Integrated Communities Energy Systems, and they saw systems thinking to be a highly valuable approach for designing future energy systems.

Adhikari et al. [2011] conclude that, in the strategic energy planning of districts, it is necessary to embody the main concepts of Smart Grid and virtual power plants frameworks. More recently, for example Sampaio et al. [2013] have considered a distributed energy generation systems platform composed of renewable and non-renewable energy alternatives, and they suggested a multi-objective optimisation model for evaluating economic and environmental goals. Tsoutsos et al. [2009] have used multi-criteria analysis to assess energy alternatives for sustainable planning, and they conclude that it can offer a platform for negotiations over the strategic plan for sustainable energy while maintaining equivocal involvement of multiple actors. Multi-criteria analysis can also support actors through all the decision-making phases by offering useful information for setting the priorities and recommending policy strategies for sustainable energy planning [Tsoutsos et al., 2009].

To summarise, there are a large number of energy system models available. According to Bhatt et al. [2010], models have been developed for the planning of large energy systems at national or regional levels, capturing simple to detailed energy system representation and top-down or bottom-up modelling paradigms. The main differences in these models include the degree of detail, in which energy commodities and technologies are presented, and the methodology for studying the dynamics of the energy system. Models have differences also in the economic approach, level of disaggregation of decision variables, time horizons used in the planning, and geographic characteristics. Models can be based on simple spreadsheet computations, or simulations of system (and subsystem) performances, and some of them include detailed optimisation frameworks to compare e.g. the use of energy resources and economic performance. Bhatt et al. [2010] state that nevertheless there are lots of different kinds of energy system models, but they are not comprehensively utilised in local level energy planning. [Bhatt et al., 2010]

When analysing the entire energy system in many kinds of urban areas, different synergy benefits can be recognised for optimal energy savings and energy system performance [Zinck Thellufsen and Lund, 2015]. For example, Lundström and Wallin [2016] identified a strong link between buildings and energy networks by concluding that, while energy conversation measures in buildings in general are valuable, also the time of year when the energy can be saved does have an impact on the primary energy efficiency and emissions savings when studying the district heating system perspective. They noted that if heat energy savings are made by increasing electricity consumption, they do not improve primary energy efficiency or mitigate global warming. Instead, energy conversation measures in buildings should be done with energy system-favourable heat demand profiles [Lundström and Wallin, 2016]. Moreover, additional integration and synergy benefits can be found from the other energy using city infrastructures and services, such as waste and water management systems, street and public space lighting, and transportation.

2.4.3 Energy flexibility and balancing

Many policies guide the development towards low carbon economy [e.g. EC, 2014a], among others by increasing the share of distributed renewable energy supply in districts. The Energy Performance of Buildings directive [EC, 2010/31] drives buildings to become nearly zero energy buildings, which transforms the traditional role of buildings from energy consumers to small energy producers – so-called prosumers [Rathnayaka et al., 2015; Picciariello et al., 2015].

In the transition towards sustainable overall energy systems, demand-side management plays an important role in keeping buildings' energy demand at a sufficient level, as well as enabling the effective use of renewable energy matching to demand [Pina et al., 2012; Manfren et al., 2011]. Kyliki and Fokaides [2015] go further by stating that future zero energy buildings are an integral part of energy networks through active participation in the operation and shifting between thermal and electric loads, and balancing of renewable energy generation and co-generation.

The flexibility in energy demand can be used for balancing and optimising the use of different energy sources available locally (and/or with low price levels from the national electricity grid) [Heimonen et al., 2012]. Among others, Lu et al. [2015] have reviewed optimal design and control methods for the complex interplay of controlling buildings' energy production, demand and storage systems. Di Giorgio and Liberati [2014] have presented a near real time load-shifting control for residential electricity consumers, enabling them to participate automatically in the demand side management programmes.

Most of the related research efforts focus on electricity balancing and trading, but e.g. Nystedt et al. [2006] have also studied heat trading through a district heating network. However, the energy matching approach seems to be relevant also in the district heating and cooling networks.

2.4.4 Evaluation of urban areas and their energy systems

To support decision-making in urban planning and sustainable urban development, various tools have already been developed for assessing urban environment and its energy performance and sustainability impacts, for example BREAAM Communities [2012], CASBEE for Urban Development [2014] and LEED for Neighbourhood development [2009], and other tools presented, for example, by Charoenkit and Kumar [2014], Sharifi and Murayama [2013] and Loiseau et al. [2012].

National assessment tools and frameworks for sustainable built environment are developed in specific projects in Finland. Typically, sustainability assessment tools are used only after urban plans are finalised, but as Wedding and Crawford-Brown [2007] conclude, it would be beneficial to use the assessment indicators already during the planning phase. The following are examples of tools developed to support urban planning during the planning process. Lahti et al. [2010] developed a tool for evaluating eco efficiency of areas in the City of Helsinki.

Rad [2010] suggested a methodology for using energy indicators in improving the quality of municipal energy planning in a more sustainable manner. Energy indicators can be useful in monitoring the energy trends and evaluating energy policies, and they can assist in developing local energy systems through knowledge exchange and learning processes between municipalities [Rad, 2010]. Eicker et al. [2015] developed criteria for assessing the energy performance of cities, where indicators were classified into four categories: 1) Integral energy concept (holistic approach and innovativeness), 2) Induced energy demand (urban and building compactness: high densities were classified as "good" in terms of building energy efficiency and performance), 3) Solar access (share of buildings "with the main orientation ±45° south, minimizing shading for PV modules or higher use of passive solar gains (in winter) were praised within the assessment"), and 4) Renewable energy supply ("efficient renewable heat distribution (e.g. by placing low consumption districts furthest away from the district heating plant)", and "the integration of photovoltaic panels in buildings or the maximum utilization of roof area for PV use") [Eicker et al., 2015].

Eicker et al. [2015] stated that cities have difficulties in effectively evaluating which urban, land use and energy concepts would be best for today and in the future, because there is often a lack of quantitative data on building energy performance as a function of urban density, building compactness and orientation, building use and supply options in the design of new cities or early scenario analysis for existing city quarters. They propose a methodology for assessing the energy demand and solar electricity supply potential as a function of the availability of geometry, building standard and use data for a large city extension in Munich, Germany. Eicker et al. [2015] learned that it is very important to analyse the building form, as the loss of building compactness increases "*the loss of building compactness increases the energy demand for heating by 10–20% while it reduces the integration potential of renewables by up to 50%*". Also, the addition of mutual shading of buildings increased the simulated heating demand by 10 %. [Eicker et al., 2015]

According to Sampaio et al. [2013], analytical tools can benefit decision-making significantly when selecting the most suitable solutions for the energy mix from the economic and environmental viewpoints. Lotteau et al. [2015] reviewed 21 recent studies for built environment LCAs on the neighbourhood scale, which all proposed their own adaptations of the LCA methodology for the neighbourhood scale. This review shows that LCA applications in the neighbourhood scale assessment are not straightforward, and that this is a relatively new study field. They highlighted the following recommendations for the neighbourhood scale LCA [Lotteau et al., 2015]:

- Systematic communication of key features: i.e. number of inhabitants, number of non-resident users, neighbourhood area, total floor area and analysis duration.
- The contextualisation: characteristics of the built environment and their influence on the buildings' energy demand should be taken into account, such as urban morphology, presence of vegetation, choice of surface materials.
- Uncertainty analysis related to long-term development of the key parameters of the neighbourhood.
- The temporal evolution of the electricity production should be accounted for, especially for low energy neighbourhoods including local renewable energy production.
- Full and comprehensive multi-criteria assessment of the built environment is already enabled by LCIA developments, and thus mono-criterion approaches should be avoided in order to prevent emission shifting.

Recently, zero energy building development has been broadening towards neighbourhoods and districts. For example, Ala-Juusela et al. [2014] have developed key performance indicators for evaluating the energy positivity level of neighbourhoods with the aim of assessing how well the neighbourhood fulfils the definition of an energy-positive district.

2.5 Energy system and service business

As described in previous chapters, the near future changes in energy systems bring challenges for the energy sector from the quickly changing business and operation environment. Energy utilities are forced to rethink their ways of doing business and operating their systems, when the pressure for increasing the share of distributed energy production grows, and the energy system needs to adapt to using hybrid energy sources.

There are already business models that could be potential for district energy systems with a high share of local, renewable and distributed energy production [Heimonen et al., 2012]. Heimonen [2007] presented different life-cycle models for building services in Finland. Currently used energy service models include also different variations of public private partnership models [e.g. Tieva and Junnonen, 2009] and the energy service related services, such as [EC DG JRC, 2010]:

- **Energy service company (ESCO)**: a company delivering energy services and/or energy efficiency improvement measures in clients' facility. The service payment is based either as a whole or partially on the achievement of energy efficiency improvements and meeting of the other potential performance criteria set. ESCO assumes the financial risk relative to energy projects and gets payment e.g. according to the extent of realised energy savings. [EC DG JRC, 2010]
- **Energy performance contracting (EPC)**: a contractual arrangement between the beneficiary and the provider (e.g. an ESCO) for a measure improving energy efficiency. The Investments in the measure are paid in relation to the contractually agreed level of energy efficiency improvements. [EC DG JRC, 2010]
- **Third-Party Financing (TPF)**: a contractual agreement that involves a third party in addition to the energy service provider and the beneficiary of the energy efficiency improvement measure. The third party provides the capital for the measure and charges from the beneficiary a fee that is equivalent to a part of the energy savings achieved a result of the measure. [EC DG JRC, 2010]

Boait [2009] presented energy services in three categories: business-to-business ESCOs, retail energy suppliers and the Local ESCOs. Boait [2009] noted that the utilisation of local energy sources could be maximised by adopting a new form of energy network charges based on the local use tariff that reflects the real use of the distribution network in conveying the locally generated energy. In addition, energy supply contracting (ESC) model has been presented by Bleyl-Androschin and Ungerböck [2009], in which the efficient supply of energy is contracted in energy units delivered.

Good et al. [2015] noted that low-carbon technologies have the possibilities to reduce energy costs and carbon emissions from final energy consumers through coupling and optimising energy commodities from traditionally independent systems (e.g. electricity, heat and gas). However, this kind of transition to distributed multi-energy system introduces complex physical and commercial interactions, and hence, the assessment of related business cases can be a major challenge [Good et al., 2015]. Cardenas et al. [2014] highlighted the fact that consumers' participation as producers or rather, as so-called prosumers, will require developing new business models in the near future. The reason for this is that prosumers will play a key role in the distributed energy production and selling of the excess capacity to the energy companies.

Different support instruments in EU-27 have been mapped by Klessmann et al. [2011]. They also studied the various barriers of renewable energy production.

2.6 ICTs for district energy systems

The evolution of energy infrastructures towards a more distributed, adaptive, predictive and market-based paradigm is enabled by ICT technologies [Manfren, 2011]. ICTs can support holistic coordination and efficient use of hybrid energy systems through multiple solutions, such as information exchange and protocols, interfaces, tools for planning, modelling and simulation, performance evaluation, collaborative development, etc. These requirements are closely linked to other developments of smart technologies, especially in the field of smart cities. A smart city can be seen as a large connected system consisting of several sub-systems, which are planned and operated in close communication and coordination among a wide range of stakeholders, experts, city officials, service providers, and end users [Sepponen et al., 2014].

Also, smart grid applications are part of the required ICT for district energy systems, although they typically focus only on electricity systems. In the smart grids, ICT is utilised in collecting information and controlling the energy system automatically by using information about the performance of energy consumers and producers with the aim of improving the system efficiency, reliability, profitability and sustainability of the overall energy system in smart cities [Kylili and Fokaides, 2015]. Smart grids support local renewable electricity production and smart electric vehicle charging, as well as energy storage use, demand response and grid balancing system [Kylili and Fokaides, 2015].

In addition to broader smart city and smart grid developments, district energy systems also have close links to the end user side through smart building and smart appliances development frameworks. Roadmaps for needed ICT research and development have previously been identified e.g. by following projects: Roadmap for Energy Efficient Buildings (REEB) [Hannus et al., 2010], Roadmap for Energy Efficient Buildings integrated to neighbourhood – ICT 4 E2B Forum [Hannus and Delponte, 2012], Roadmap for ICT for Energy Efficiency of smart buildings, smart grids, smart manufacturing and smart lighting – REViSITE [Hannus et al., 2012].

Karmers et al. [2014] have developed a framework for assessing and guiding the use of ICT solutions so as to reduce energy use in cities with identifying ICT related opportunities, pilots and existing solutions. Manfren et al. [2011] highlight that, besides the optimal energy system sizing and dispatch strategies determination, smart tools have an essential role in providing valuable insights into system monitoring and management strategies in real life applications. Dynamic energy management systems can enable the distributed control of the future decentralised energy system, where multi-commodity network flow models enable efficient management of multiple commodities over the arbitrary energy networks [Manfren, 2011]. For example, Velik and Nicolay [2015] introduced an automated optimisation approach to optimal energy management strategies in grid-connected, storage-augmented, photovoltaic-supplied prosumer buildings and neighbourhoods. These kinds of solutions require suitable interfaces and protocols for the exchange of energy and information [Manfren, 2011].

3D city models enable advanced analysis and visualisation tasks in a variety of application domains, such as urban planning and environmental simulations [Gröger and Plümer, 2012]. ICT can also support improved participatory planning processes for sustainable urban development by offering means for planning data management and citizens', and stakeholders' engagement [Stratigea et al., 2015]. The role of urban planners is crucial in this development.

2.7 Towards integrated low carbon district energy systems

According to the literature review, there is an urgent need to improve the sustainability of districts, and in this energy systems play a major role. At the same time, the operation environment of district energy systems is changing, when buildings are becoming more energy efficient and the use of local renewable and distributed energy supply increases.

Energy systems need to be able to cope with hybrid energy sources and technologies, and as a consequence, their planning, evaluation and assessment with integrated approach is crucial. Therefore, energy systems need to be taken into account already in the urban planning decisions. These near future changes also require energy utilities to react to the changing business environment, and new business opportunities are expected to emerge from the transition to hybrid energy systems. ICTs enable the planning, construction and operation of integrated district energy systems with the aim of maximizing the system efficiency and optimal use of energy sources. The key issues from the literature review are summarized in Table 1.

The literature review shows the significant role of energy systems in improving districts energy efficiency and reducing environmental impacts. Following this, the research question is: How much and by what means can districts' energy efficiency and sustainability be improved? And more specifically, how could district energy and emission analysis support designing more sustainable and energy efficient districts? Even though there are many modelling and simulating district energy systems, but still in the practical work urban planners are typically making land use decisions without sufficient knowledge of the impacts of the different design alternatives to the energy efficiency and energy systems in the planned area. Urban planners need practical methods and tools that enable fast and easy assessment and comparison of different design alternatives and their impacts on the energy efficiency and greenhouse gas emissions in different case areas. These challenges and lack of expertise in local communities in interpreting the recommendations of local energy regulation and planning instruments are also recognised e.g. by Manfren et al. [2011]. And furthermore, the second research aim is to propose how to organise new business and service concepts for district level energy solutions.

Table 1. Key issues and open questions summarised from the literature review.

	Reference	Key issues	Open questions and further development points
Sustainable urban development	Mohareb and Kennedy, 2014	Cities need locally suitable carbon reduction strategies.	Fundamental changes in energy supply and demand services must be considered in the long-term policy goals. Radical carbon reduction targets needed from urban policy makers.
	Eicker et al., 2015	Cities have difficulties in effectively evaluate the best suitable urban energy planning concepts.	Buildings' zero energy balance would often require high energy efficiency, on-site RES & more central supply.
	Zaron and Verones, 2012	Spatial planning strategies and policies should be closely linked together with urban energy efficiency actions. New objectives for planning practices in terms of urban quality, equity, and energy efficiency.	Local level needs improved performance-based planning practises and solutions for including energy goals in spatial planning and urban policies to achieve low carbon and energy efficiency goals.
Holistic district energy system	Sampaio et al., 2013	Identification of distributed energy generation alternatives and assessment their inclusion on city's energy supply can support municipalities and even government in establishing energy policies.	Analytical tools support decision making significantly in the choice of the most suitable solutions for the energy mix from the economic and environmental viewpoints.
	Mirakyan and De Guio, 2013	A generic integrated energy planning procedure with systematic and holistic way.	Methods and tools have not yet been combined to manage all of the integrated energy planning tasks. Supporting planning tools are lacking from the 1st phase (preparation and orientation).
	Huang et al., 2015	Numerous computer tools and models are available for communities' energy planning already.	Planners would benefit from new systematic and effective assessment indicators and methods for analysing the community energy systems, when setting goals and developing proposals.

Business concepts	Good et al., 2015	Low-carbon technologies have the possibilities of reducing energy costs and carbon emissions from final energy consumers.	Transition to a distributed multi-energy system introduces complex physical and commercial interactions, and hence, the assessment of related business cases can be a major challenge.
	Cardenas et al., 2014	Energy consumers becoming producers or rather, as so-called prosumers.	Requires new business models.
ICT supporting holistic district energy systems	Manfren et al. 2011	A paradigm shift from centralised energy supply and one-way energy distribution to a hybrid energy source supply with increasing the share of distributed energy supply from buildings and districts.	A strong need to develop innovative and interoperable models for energy systems design and techno-economic feasibility evaluation. Furthermore, these models have to be connected with tools and ICT solutions, e.g. for the process monitoring and control.
	Bhatt et al., 2010	Municipal energy systems need to be considered as a whole, including interactions and interdependencies among the system components → a comprehensive view of the overall complex energy system and its performance.	Energy systems would greatly benefit from the systemic approach and long-term strategic planning. Nevertheless, there are lots of energy different kinds of energy system models, still they are not comprehensively utilised in the local level energy planning.
	Kyliki and Fokaides, 2015	ICT is utilised in collecting information and controlling the energy system automatically by using information about the performance of energy consumers and producers with the aim of improving system efficiency, reliability, profitability and sustainability of the overall energy system in smart cities.	Zero energy buildings will become an integral part of a future smart city with on-site renewable energy production and intelligent energy management as an active part of a smart grid and city's energy system.

3. Methods

3.1 Overview

This chapter presents the research approach used to ascertain how to best support the planning and management of energy efficient and low emission district energy systems. The main research themes were: 1) district energy analysis (consisting of requirement analysis, energy scenario specifications, and energy scenario analysis), and 2) business concepts for district energy systems and services. A summary of the overall research approach is visualised in Figure 6. All methods were based on theory and experience from previous research though a literature review. The primary challenge was to find practical ways to support urban area development.

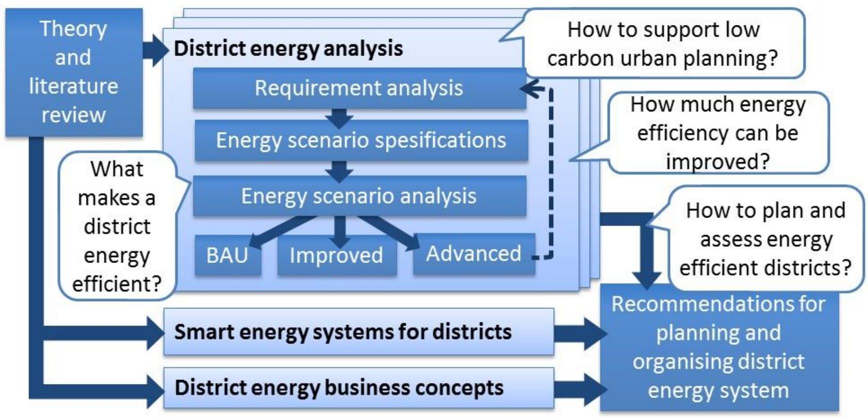


Figure 6. Overall research approach and the main research questions

This dissertation consists of five published research papers I–V, which are reprinted in Appendices A–E. These research papers and their roles in this dissertation are summarised in Table 2. The dissertation summarises their results and suggests recommendations for the planning and organising of district energy systems and services.

Table 2. Summary of papers and their roles in this dissertation

Objectives	Research questions	Methods used	Paper	
Method for district energy analysis Analysis of building energy demands	How to assess energy saving potentials in buildings and districts?	1 case study Energy calculations	I	Energy saving potentials of Moscow apartment buildings in residential districts
Comparison of district energy demand and supply scenarios and their emissions to air	How much and by which means can energy and emissions be reduced when renovating districts?	Expert analysis for the scenario development Energy and emission analysis in a case study	II	Energy and emission analyses of renovation scenarios of a Moscow residential district
Assessment tool development District energy and emission analyses	How to assess energy efficiency of districts?	Literature review, interviews, 6 case studies	III	Energy efficiency rating of districts, case Finland
Collection of business concepts Key performance indicators Barriers to business and services	How to organise new district energy business concepts with hybrid energy sources?	Stakeholder analysis Business canvas Expert workshops	IV	Development of business concepts for Energy Hub systems
Energy and emission analysis method and tool development District energy and emission analyses	How to support sustainable urban planning with energy and emission analysis?	Literature review 2 case studies	V	Low carbon urban energy planning in two Finnish cases

The research process and the main research questions are illustrated in Figure 7. The detailed district energy analyses are presented in Papers I–III, and in Nystedt and Sepponen [2011], Nystedt et al. [2010], Nystedt et al. [2012] and Paiho and Palos et al. [2013]. This dissertation derives learnings and conclusions from these 14 real life urban area cases in Finland and Russia. These detailed analyses have been establishing the foundations for developing guidelines and recommendations for low carbon district energy planning in Paper V, and for district energy service business concepts in Paper IV.

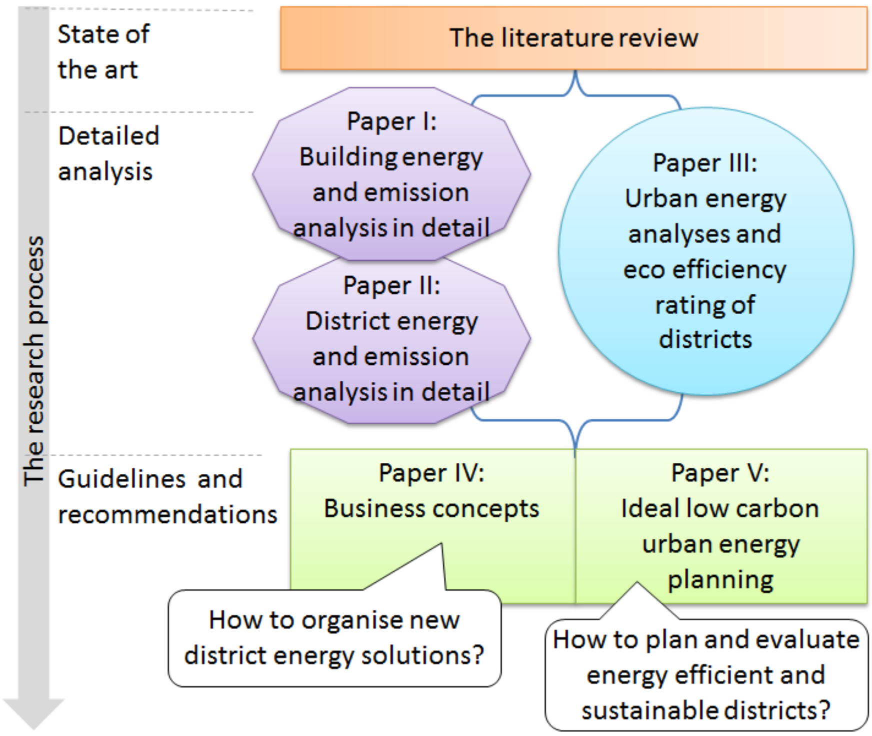


Figure 7. The research process and main research questions.

The research methods are described in following sections. Energy analysis consisted of the following three steps: requirement analysis (Section 3.2), energy scenario specifications (Section 3.3), and energy scenario analysis (Section 3.4). Methods for business concept development are presented in Section 3.5.

3.2 District energy requirement analysis

Users' and stakeholders' needs and requirements were the starting point of district energy analysis. The municipality representatives, such as urban planners and municipality officials and decision makers, were interviewed to elicit their expectations and needs regarding the planning of districts and their energy solutions. Interviews also strongly supported collecting the required base data for the district energy analysis. Additional stakeholder and expert questionnaires used both for the district energy analysis, as well as in the development of business concept and the road map, are described in in Papers III, IV, and V in the appendices.

The requirement analysis of district energy analysis began by forming an overall understanding of the district. This was done by interviewing urban planners or other city officials according to the general interview schema presented in Table 3.

Table 3. The general schema of interview questions regarding overall information about the district.

Interview questions	***Relation to district energy analysis***
Location of the area	Retrieving climate data for analysing energy demand as well as solar and wind energy yields.
Map of the area, visualisation of the district plan	Supports acquiring an overall understanding of the area, and analysing the potential district heating network structure.
Number of residents in the area (and/or number of jobs)	Supports analysing the energy demand of the area.
The areal density of the district plan	Supports analysing the energy demand of the area.
Is it a ground water area?	Effects on potential use of ground heat pumps.

Urban planners were also familiar with the status of existing and planned buildings in the district studied. Information about these buildings was needed for analysing the energy demand of the district. Questions used for collecting building related information are shown in Table 4.

For the energy supply side analysis, the interview with local energy company representatives was highly useful. They typically have the best understanding of the state of the local energy system and used energy sources and distribution networks. Here the main target was to describe the city's current energy production plants, energy sources used and related future plans. In several cases, it was also useful to learn about energy suppliers' views of future needs for ensuring a sufficient level of thermal energy production capacity in the city. Some renewable energy supply methods have also boundaries, which were discussed. For example, the boundaries of utilising ground or water source heat pumps were studied regarding the type of soil and whether the area is located in a ground water area or not. These questions were also discussed with urban planners and decision makers in some cases.

Table 4. Interview questions for urban planners related to buildings in the district.

Interview questions	*Relation to district energy analysis*
What kinds of buildings exist now and/or are planned in the area?	Needed for the energy analysis of the buildings. Examples of building types: residential buildings (e.g. apartment building, row house, single family house, townhouse), office buildings, service buildings (such as school, hospital, day care centre, shops), and industrial areas (e.g. small scale industrial buildings) etc.
When were the existing buildings constructed?	Reveals the minimum level of energy efficiency of buildings based on building regulations at the time.
What are the energy efficiency targets for the new buildings?	Supports energy demand analysis. E.g. targets required by building construction regulations, or better (low energy or passive level, or (nearly) zero energy buildings.
The floor areas for different types of buildings.	Base data needed for the energy demand analysis.
The number of different types of buildings.	Supports energy analysis for the entire district.
Is there on-site energy (usually heat) production in the buildings?	Supports energy supply side analysis.
Do the buildings have smart meters or real time energy monitoring systems?	Supports energy demand analysis, smart meters can have an effect on the energy demand.

In some research cases, the district energy analysis was broadened to take into account other energy demands in the area, such as passenger transportation, street and other outdoor lighting, and waste and water systems. For city infrastructures, the requirement analysis focused on identifying the existing and/or planned capacities and needs for these city services and maintenance. To identify the passenger transportation requirements, the following questions were used:

- Transportation system in the area: Are you using or planning to use any solutions for increasing the share of pedestrian and cycling and use of public transportation? Some examples are: separate, high quality and secure cycling and pedestrian routes, parking of cycles, centralised car parking, availability of public transportation in the area (busses, trams, metro, and train).
- What daily services exist and/or are planned nearby or in the area, such as grocery shops, children's day care, schools, etc.?

As a result of the stakeholder requirement study, an overview and understanding of the studied district was formulated, and the basic structure and data needs for each case area were collected (see Table 5). In addition to this information set, a plan of the district (a map) was needed to support gaining a comprehensive understanding from the studied area.

Table 5. The structure of case descriptions and required base data.

Base data of the case	*Description of the base data*
Total area	Total surface area of the district (in m^2)
Number of residents	Estimation of number of residents (persons)
Building types in the district	Description of building types in the area
Floor areas of buildings	Total floor areas of each type building
Number of buildings	The estimated number for each building type
Density of the district	Areal density value used in urban planning, the ratio of total floor area of buildings to the total surface area of the district
Location of the district	Location information, information about local climate
Used energy sources	Available and used energy sources in the area
In the ground water area?	Is the district in the ground water area (yes or no)?

3.3 District energy scenario specifications

One of the key areas in this study was the comparison of different energy system scenarios based on urban plans of the area. The district energy systems of the case areas were analysed using different energy system scenarios. The energy scenario analysis included comparing scenarios for buildings' energy efficiency levels and potential energy sources and technologies utilised. This enabled comparing business-as-usual (BAU) scenario to more improved and advanced scenarios e.g. with higher energy efficiency in buildings and increased use of local renewable energy sources or other energy sources with lower emissions. An overview of the developing the specifications for district energy scenarios is shown in Figure 8.

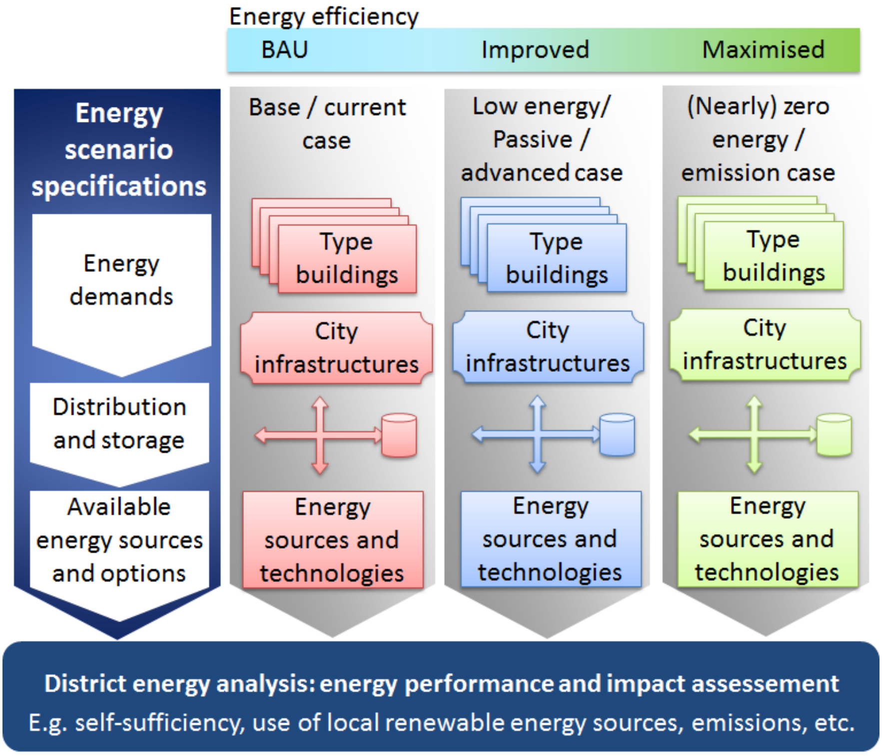


Figure 8. General overview of developing energy scenario specifications.

Energy scenarios were specified for each case starting from the energy efficiency level of buildings. Depending on the identified requirements of stakeholders in each case, the energy demand scenarios were typically based on different energy efficiency levels for buildings. As an example of a typical case, energy demand is compared in: 1) current or business-as-usual state (e.g. according to national building regulations), 2) low energy buildings, and 3) passive buildings. Some case analyses go beyond this by evaluating more advanced scenarios, e.g. nearly zero energy buildings. The energy demand analysis studied the average energy efficiency levels of different policies and targets for buildings' energy efficiency. This study aimed to show what these different policy levels would mean in real life case areas. Some of the cases also included energy use of waste and water management systems, or the passenger transportation.

Secondly, district energy scenarios included the comparison of potential energy distribution systems with varying efficiency levels, especially related to district heating systems and their network design choices. In some case studies, the requirement analysis exposed the need to compare different urban plans and related effects on the efficiency of energy distribution.

Similarly to energy demand scenario building, the energy supply scenarios in the energy analysis consisted of comparing current or business-as-usual state to other available and potential energy sources in the case area. The energy sources compared included electrical heating, district heating (from different energy sources), heat pump systems, biomass boilers, solar energy, buying electricity from the national grid, and wind energy. The realistic options and possibilities for different energy supply systems were compared based on the stakeholder requirement analysis and system boundaries of the local environment in each case study analysis.

3.4 District energy scenario analysis

The main targets of the energy analysis were to form an overview of the average energy consumption in the area, to identify available and potential energy production resources and their capacities. As a result, the overall energy efficiency and potentials for improving it in the district could be evaluated. In addition, in some cases the analysis also included e.g. comparing of alternative urban plans for the case areas.

The general district energy and emission analysis methodology is visualised in Figure 9. Firstly, the energy consumers in the area were assessed, including e.g. energy simulations of buildings, which enabled forming the state-of-the-art, or in other words, the business-as-usual (BAU) scenario. Secondly, different improvement scenarios were defined for comparing varying levels of energy efficiency in buildings. Then alternative potential local energy sources were identified. The analysis continued by assessing the used and potential energy supply systems, including e.g. energy distribution losses. And finally, the life cycle emissions were calculated for each district energy scenario. These steps are presented in sections following.

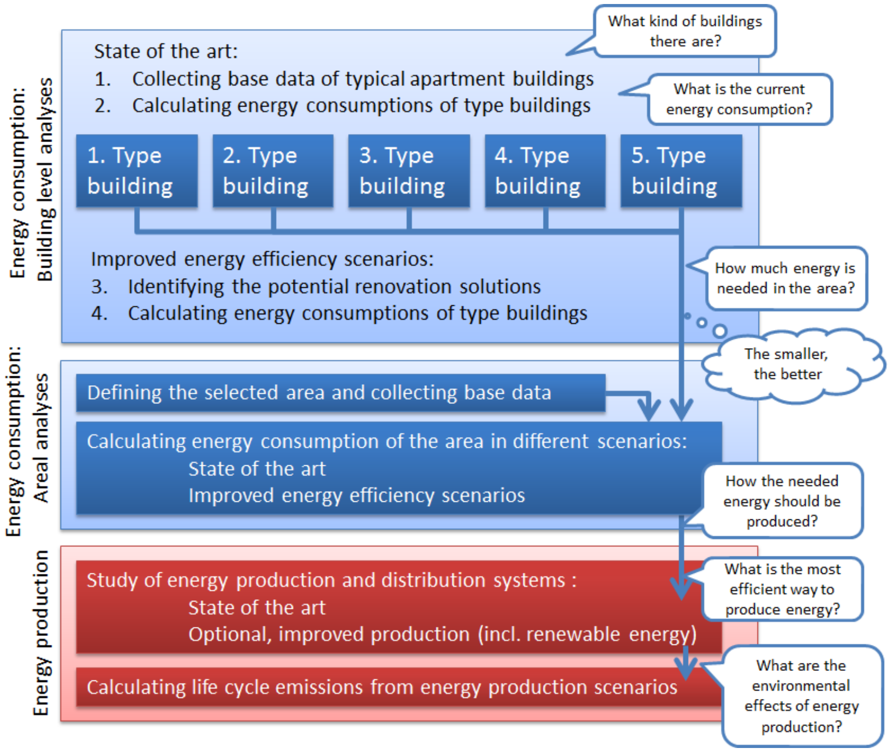


Figure 9. The basic process for making districts' energy and emission analysis (Author's own figure from Paper II: Paiho et al., 2013).

3.4.1 Methods for buildings' energy demand analyses

The energy demand of buildings can be studied in many ways. An often used method is to simulate the energy demand of average type building models representing typical buildings with different purposes (e.g. residential, service, or office building) and different age and/or energy performance groups. This kind of approach is used among others in the REMA model by Tuominen et al. [2014], where buildings' energy performance was simulated in-depth with IDA Indoor Climate and Energy (ICE) application for dynamic multi-zone simulation enabling studying of thermal indoor climate and the energy consumption of the entire building [IDA ICE, 2014]. This REMA model uses the same base data for buildings' energy demand as is used in Paper VI. IDA ICE enables in-depth energy simulation with short time steps (e.g. annual energy demand throughout the entire year).

Papers I – III had similar base with simulating buildings' energy demand as is used in the REMA model. However, instead of using IDA ICE, the energy demand of building scenarios are simulated with a simpler building's energy demand estimation tool called WinEtana. This tool is developed by VTT [Kosonen and Shemeikka, 1997]. The tool enables a quick calculation of energy demand based on (at the minimum) following base data: floor area and shape of the building, number of the floors, the thermal performance of the building envelope (as U-values), air tightness factor (n_{50}), average water consumption, and electrical equipment used and its energy performance classes; as well as the location of the building and the local monthly climate conditions. The tool calculates the energy performance of the building at the monthly level, which is in many cases detailed enough for supporting decision making at the pre-design phase and when comparing overall energy performance at the district scale.

Paper III [Hedman et al., 2014] presented one in-depth analysis of a single case area, but mostly it focuses on the energy efficiency rating tool for districts on a more general level. The energy efficiency rating tool estimated energy efficiency based on building energy class certifications, and hence offered an even simpler approach, which enabled making of pre-design estimates, if users do not have much information at all from the buildings planned in the area.

3.4.2 District energy demand analysis

Energy demand analysis at the district level included the energy demand of buildings (coupled with the number of each type building represented in the case area). Other possible energy demands were taken into account in some case studies, e.g. the energy demand of water and waste management systems (as in Papers I and II), energy demand of transportation (as in Paper V), and street lights (as in papers I and II). Other energy demands might come e.g. from industrial areas, but these kinds of districts were excluded from this study.

One specific focal point was the energy distribution system, and its losses. The energy distribution losses were added up to the total amount of energy supply capacity needed by a district. The share of distribution losses for district heating were studied in Papers III and V, stating that the share of distribution losses of district heating network varied based on the density of energy consumption in comparison to the length of the areal heat distribution network. This assessment method seemed to be more detailed than the often used simplistic way of assessing energy losses of heat distribution in areal energy analysis based on average national district heating network losses.

Primary energy use of districts can be evaluated with a “cradle-to-grave” analysis [Gustavsson et al., 2011; Johansson et al., 2007]. Another way is to use energy conversion factors, which are politically established on the national level, e.g. for Finland in the building regulations in 2012 [Ministry of Environment, 2012]. This approach is taken in Paper III employing Finnish energy conversion factors for the different energy sources used.

3.4.3 Life cycle analysis for emissions and its boundaries

Environmental impacts of energy systems were evaluated in this study with life cycle assessment (LCA), which is a method for assessing “environmental aspects and potential impacts, (e.g. use of resources and the 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)". LCA study consists of four phases: 1) the goal and scope definition phase, 2) the life cycle inventory analysis phase, 3) the life cycle impact assessment phase, and 4) the interpretation phase". [ISO, 2006]

To be more specific, the approach used in this study was attributional LCA, which Finnveden et al. [2009] define by "its focus on describing the environmentally relevant physical flows to and from a life cycle and its subsystems". The main approach used was hybrid LCA combining process-LCA to Input-Output LCA.

The emission analysis in this study focused on energy sources used and includes the LCA of used or optional energy sources, needed energy supply, distribution infrastructure and other related processes. The emissions presented for different cases and scenarios did not include an LCA of buildings and their materials, nor emissions from transport or any other city infrastructures.

The emission calculations for all case studies were based on emission factors retrieved from GEMIS software (Global Emission Model for Integrated Systems) [IINAS, 2014], which have a large database of many energy technologies and their emissions in different countries. These emission factors consisted of emissions caused by the significant processes and products needed for producing a unit of heat or electricity. Allocation of emissions to CHP plants was based on partial substitution method, as detailed in Paper II.

The emissions included in the study were: greenhouse gases (CO_2 equivalent emissions), SO_2 equivalent emissions, TOPP equivalent emissions (tropospheric ozone precursor potential), and small particulates. As detailed in paper II, CO_2 equivalent emission is a total measure, in which the emissions of different greenhouse gases are summed up according their global warming potential (GWP) factor. SO_2 equivalent signifies the total acidification potential, which is the result of aggregating acid air emissions. In the calculation of SO_2-equivalent emissions, the GEMIS tool includes SO_2, NOx, HF, HCl, H_2S and NH_3. TOPP-equivalent signifies tropospheric ozone precursor potential. It is the mass-based equivalent of the ozone formation rate from precursors, measured as ozone precursor equivalents. The TOPP represents the potentially formation of near-ground (tropospheric) O_3, which can cause smog. TOPP includes emissions of NO_x, NMVOC (non-methane volatile organic compounds), CO and CH_4. Particulates have a significant effect on the local air quality level [EPA, 2012]. [IINAS, 2014; Fritsche and Schmidt, 2008]

3.5 Development of business concepts for energy systems of districts

The overall methodology for developing business concepts for Energy hub systems consisted of the following actions [Paper V]:

- An analysis of main stakeholder groups was carried out so as to understand the key players and their roles and needs in energy business.
- A questionnaire was carried out so as to identify the needs of stakeholders, especially end users and service providers; this gave an indication of the services and business models.
- The analysis method was modified from the Osterwalder's business canvas [Osterwalder and Pigneur, 2010].
- A list of possible concept level models was developed in a workshop. This list is called a cookbook: a collection of business concepts. The concepts were kept simple and focused on one stakeholder at a time.
- The analysis was carried out for all business cases.

3.5.1 Structure of business concept descriptions

One of the commonly used approaches in analysing business and service concepts is the Osterwalder's approach [Osterwalder and Pigneur, 2010] for describing the product, customer interface, infrastructure management and financial aspects in nine different subtopics. In this dissertation, the Osterwalder's model was simplified by choosing the main elements of the model in the analysis. The selected analysis elements are listed in Table 6. All developed business concepts in Paper V were described according to this structure. In addition, each concept was visualised by showing stakeholders and their main interactions related to the business concept.

Table 6. Structure of the business concepts.

Elements	Description
Title	The essence of the business model in a few words.
Business idea / objective	The objective of the business model.
Offer / value proposition	The service/product offered in a few sentences.
Customer	Who will use the service/product?
Seller / Service provider	Who will offer the service/product?
Earnings / revenue model	Who pays, where does the money come from, and what is bought? Who is the owner of this business?
KPIs	KPIs to measure the success of the concept. See 4.1.2.
Costs and benefits	What investments are needed? What are the costs and benefits?
References	References to similar models studied or applied.

3.6 Summary

The research process with the published papers I–V and the related sections in this dissertation are shown in Figure 10. The literature review is in Section 2. District energy analyses of case studies are published in Papers I – III, and they are summarised with other additional case study learnings in Section 4. These case studies were building the base for the ideal urban energy plan and its assessment framework and related tool development, which are described in Paper VI and summarised in Section 4.4. Developed business concepts are discussed in Paper V and in Section 5. The lessons, challenges and other issues raised are discussed in Section 6, and the concluding recommendations are given in Section 7.

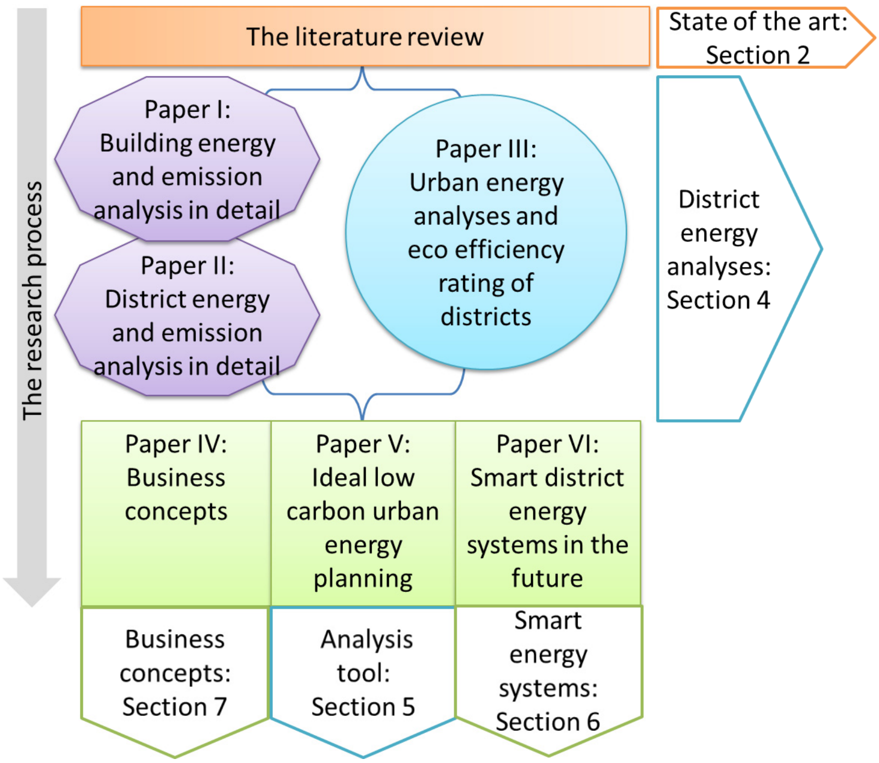


Figure 10. The research process in Papers I–V and the related sections in this dissertation.

4. District energy analyses

The literature review confirmed the importance of integrating energy issues into urban planning and development when targeting sustainable, efficient and low emission urban areas [e.g. Zaron and Verones, 2012; Mirakyan and De Guio, 2013; Yamagata and Seya, 2013; and Eicker et al., 2015]. In this dissertation, energy system and urban planning alternatives affecting the districts' energy efficiency and sustainability are studied and evaluated in Papers I–III and V. Prior to these research publications, Nystedt and Sepponen [2011] presented a concept for integrated, ecological urban planning. This concept was developed for St. Petersburg in Russia, but the main elements are applicable internationally. The concept [Nystedt and Sepponen, 2011] aims at eco efficient, functional and comfortable urban areas through integrated urban planning. This requires that already from the beginning of the urban planning process the following key elements are taken into account: dense structure of the urban area, local environment and basis, energy efficient buildings, renewable energy production, sustainable transportation solutions, waste and water management and social facts, as presented in Figure 11.

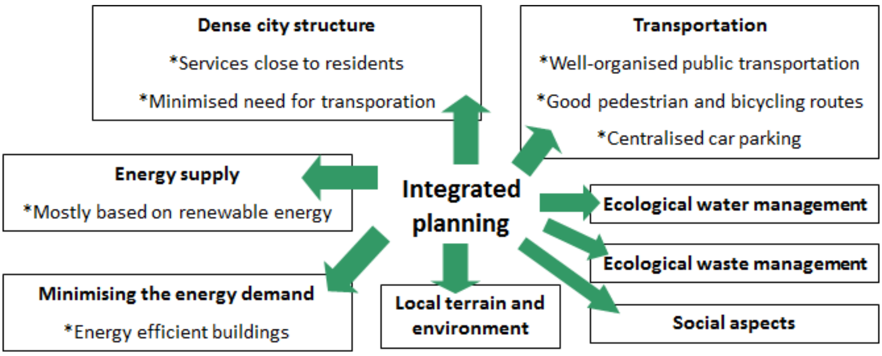


Figure 11. The basic elements of integrated urban planning. [Authors own figure in Nystedt et al., 2010].

4.1 Overview of the analysed district energy scenarios

The district energy analysis began with the requirement analysis (as described in Section 3.2), and making energy scenario specifications (Section 3.3). Then, the district energy scenarios were analysed, which resulted in a comparison of business-as-usual (BAU) with improved and advanced scenarios. The work flow for each district energy analysis followed the process shown in Figure 12 and the methodology described in Sections 3.2, 3.3 and 3.4.

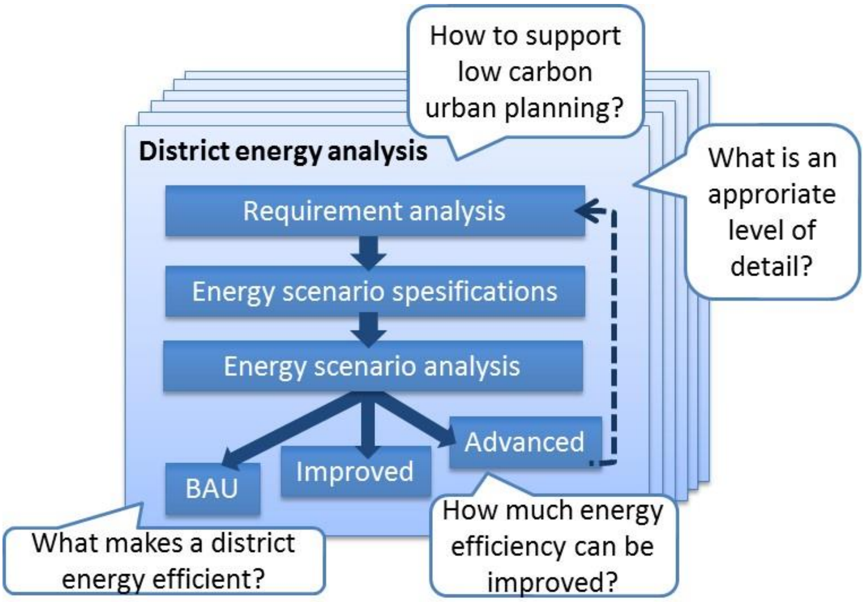


Figure 12. Work flow of the district energy analysis.

All the case analyses had an overall target to study by what means and how much energy demand and emissions could be reduced in the specific case area, with the final aim of planning efficient and sustainable urban areas. The analysis results compared included energy demand of buildings and the whole district, and the different available energy supply alternatives and their emissions to air (CO_2 equivalent emissions, SO_2 equivalent emissions, small particulates, and TOPP emissions). This was done by comparing the BAU situation to more improved and advanced scenarios e.g. with higher energy efficiency in buildings and increased use of local renewable energy sources or other energy sources with lower emissions. Some of the cases also included energy use of waste and water management systems, or passenger transportation.

4.2 Summary of the case areas

The district energy analysis was carried out for 14 real life urban area cases in Finland and Russia. The district cases studied are summarised in Table 7. The case studies are previously published in Papers I–III and V, and in research reports: Nystedt et al. [2010], Nystedt et al. [2012] and Paiho et al. [2013]. Cases 1–12 were building the base for developing a framework and an assessment tool for district energy analysis (Section 4.4), which is tested in cases 13 and 14. Examples and lessons of these cases are described shortly in this section to highlight their specialities and different aspects.

Table 7. Summary of the case areas and their main characteristics.

No.	*Case*	*City*	*Development state and type*	*Inhabitants*	*Special notes and highlights*	*Published in*
1	Saarinen	Toivakka, FI	New residential area	85	Basic energy analysis study	Sepponen et al., 2010
2	Säynätsalon kouluranta	Jyväskylä, FI	New residential area	250	District heating losses; effects of building types	III: Hedman et al., 2014
3	Öijänniemi	Kannonkoski, FI	New area, recreational	100 users	Cottages, effects of saunas	Nystedt et al., 2012
4	Kaistinmäki, in Kintaus	Petäjävesi, FI	New area, mixed use	200	Comparison of 2 plan alternatives	Nystedt et al., 2012
5	Könkkölä	Jämsä, FI	New area	180	Residential area	Paiho et al., 2013
6	Kyöpeli	Multia, FI	New area	180	Mixed use	Sepponen et al., 2010
7	Koukkuranta, in Vuores	Tampere, FI	New residential area	1100	Hybrid energy sources	Paiho et al., 2013
8	Ecograd 1	St. Petersburg RU	New area, mixed use	20,000	Combined energy analyses to eco efficient urban planning	Nystedt and Sepponen, 2011
9	Ecograd 2	St. Petersburg RU	New area, mixed use	11,500		Nystedt et al., 2010
10	Ecograd 3	St. Petersburg RU	New area, residential	1750		Nystedt et al., 2010
11	4th Microrayon of Zelenograd	Moscow, RU	Existing, renovated area	13,800	Most detailed analysis. Street lightning, waste and water management	I: Paiho et al., 2013, II: Paiho et al., 2014
12	Vartiosaari	Helsinki, Fi	New area, residential	5,000–7,000	SunZEB concept, Seasonal thermal storage	Paiho et al., 2015
13	Eriksnäs	Sipoo, FI	New/ infill construction		Test cases for Kurke tool (see also Section 5)	V: Hukkalainen et al., 2017
14	Kivistö	Vantaa, FI	New area			

Ten cases deal with districts located in Finland, and four cases are located in Russia. The first seven cases contributed to this dissertation and the development of the district energy and emission analysis methodology and tool by helping to create understanding about how to do such analysis in practical cases and what different aspects need to be considered. The following three cases (8 - 10) from Russia increased understanding about using same approach in another country with different operation environment. Case number 11 in Russia and related publications I and II set the base for describing the energy and emission methodology with using scenario comparison approach developed. Case 12 included specially a detailed comparison of energy storage options. Cases 13 and 14 were used to test the developed energy and emission analysis tool called Kurke, as described in publication V. The Russian cases were also used in this dissertation to understand and show the potential of using this method in other countries, if appropriate base data is available.

4.2.1 Case 1: Saarinen, Toivakka, Finland

The Saarinen neighbourhood is located in the municipality of Toivakka in Central Finland. The base data of the case is presented in Table 8, and the plan of the district is shown in Figure 13. Municipality representatives identified that one of the main targets for the area was as low a carbon foot print as possible. The area was built between 2011 and 2013, and it had a small family house exhibition in 2013 with a focus on eco and energy efficiency.

Table 8. Base data for Toivakka, Saarinen area. Abbreviations refer to Figure 13.

Base data of the case	*Description of the base data*
Total area	Approximately 5 ha = 50 000 m^2
Number of residents	85 residents
Building types and floor areas in the district	19 single family houses of 125 m^2 (AO) and 1 row house of 240 m^2 (3 apartments, á 80 m^2) (AP). Plot areas ranging from 1360–2260 m^2. In addition, in the centre there is a small area reserved for the maintenance of infrastructure-related services (ET) and parking for the small boat harbour area.
Density of the district	0.2
Location	Central Finland. Next to Saarinen lake (depth < 2 m).
In the ground water area?	Not in the ground water area.

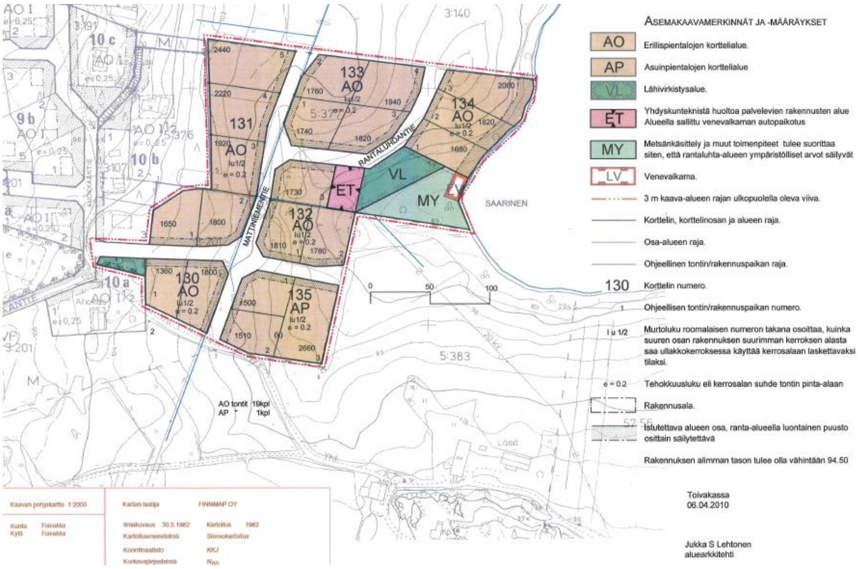


Figure 13. The plan of the Saarinen area in Toivakka [City of Toivakka, 2010].

The energy demand scenario analysis was done for two building types: a single family house of 125 m^2 and a row house of 240 m^2 (3 apartments, á 80 m^2). The average building model floor areas were defined from the stakeholder interviews. The building parameters are defined in Appendix F: in Tables F1 and F2 and in Figure F1.

Three energy demand scenarios were studied: the current level according to Finnish building regulations in 2010, and low energy buildings and passive buildings. The energy demands of these two types of buildings were simulated using VTT's WinEtana tool, [Kosonen and Shemeikka, 1997], and the building energy demand results are shown in Appendix G in Tables G1 – G4.

The energy demand of different energy efficiency level scenarios is summarised from the building energy simulations in Table 9. According to these simulations, the heat energy demand can be reduced significantly when the energy efficiency level of buildings is improved. This change is mostly due to reducing the space heating need in buildings. There are some possibilities of reducing the electricity demand also, but the expected savings are much smaller (approximately 6%), which is achieved by increasing the energy efficiency of electrical appliances and lighting. However, in the simulated buildings the electrical use of HVAC increases when the heat recovery from air exchange is improved. The district heating supply (in Table 9) is summarised from total heating demand and district heating network losses that are assumed to be 9% of the total heat demand [Klobut et al., 2009].

Table 9. Results of energy demand simulations for different energy efficiency level scenarios.

Energy demand for the entire area	Heating demand [MWh/a]	Decrease in heating demand in 2010 level [%]	District heating supply [MWh/a]	Electricity demand [MWh/a]	Estimated district heating power [kW]
2010 building	225.66	-	248	107.4	138
Low energy building	136.60	39	150	100.8	97
Passive building	100.22	56	110	100.8	77

The energy supply options studied in Toivakka are summarised in Table 10, and the detailed calculations are reported in Sepponen et al. [2010]. As these results show, if ground source heat pump system were implemented as a neighbourhood level system, it would require only 7–15 bore holes in total, depending on the energy demand level of buildings. If ground source heat pumps were used in each building as a separate system, it would require in total 20 bore holes, but on the other hand there would not be any need to build a local heat distribution grid and the total additional electricity demand would be lower than for the neighbourhood level system. If small scale CHP production were utilised, then the share of electricity supplied from the plant reduces in the scenarios with improved energy efficiency of buildings. This can imply that small scale CHP might not be so favourable option in future efficient neighbourhoods with low heat demands, as its investment costs are also typically significantly high.

District heating could be efficiently paired with solar thermal production in the summer, when the efficiency of the boiler is low due to low energy demand. This could enable raising the total heat production capacity of the boiler to cover also the high heat demands in the winter with appropriate efficiency of the heat boiler.

Table 10. Summary of comparisons for energy supply options in different energy demand levels in the Toivakka case.

Energy supply options	*Comparison*			*Notes and assumptions*
	2010 buildings	*Low energy buildings*	*Passive buildings*	
District heating with - wood chips (80% of the heat) MWh/a - peak load supply (20%)	 198 50	 120 30	 88 22	Assumption: 80% with wood chips, 20% with peak load supply (e.g. electricity) [Koskelainen et al., 2006, p. 323].
Water source heat pump - Length of the heat collection pipe - Electricity demand added [MWh/a]	 2,215 m 82	 1,341 m 50	 984 m 36	Heat pump for the district from the Saarinen lake, although this was rejected in practise due to the low depth of lake (less than 2 metres).
Ground source heat pump for district - Number of bore holes - Electricity demand added [MWh/a] Ground heat pump for each building - Number of bore holes in total - Electricity demand added [MWh/a]	 15 82 20 72	 8 50 20 42	 7 36 20 32	Both neighbourhood and building level heat pump systems possible. Assumptions: clay ground with heat yield of 55 kWh/a per metre of heat collection pipe. COP 3. Heat collection depth: 200 m. [SULPU, 2003]
Small CHP - 50 % of the heat demand MWh_h/a - 50 % from peak heat boiler MWh_h/a - Electricity from CHP MWh_e/a - Share of electricity demand from CHP	 124 124 62 58%	 75 75 38 37%	 124 124 62 27%	Production according to the heat demand. Perhaps with renewable fuels. Bigger investment costs than for district heating boiler. Wood chips as fuel. The construction rate (electricity production/heat production is 0.5) [GEMIS, 2010; Koskelainen et al., 2006].
Local biogas for a small CHP plant - Electricity production MWh_e/a - Heat production MWh_h/a	 2,310 3,300 (10 times bigger than the heat demand of the area)			Local biogas from farms available 6600 MWh/a. Suitable e.g. for CHP (assumed: construction rate 0.35). Challenges from system efficiency: most efficient to utilise the biogas on-site or close to farms, but the area studied is farther away.

Life cycle emissions from the energy production were analysed with the GEMIS tool (Global Emission Model of Integrated Systems [GEMIS, 2010]), including emissions from manufacturing the energy production utility, fuel manufacturing and transportation, and the energy production process. Emissions were analysed for all three scenarios. Carbon equivalent emissions for electricity and heating in the Toivakka case are shown in Figure 14. It shows that smallest carbon emissions are from biogas-based energy supply, and from the combination of district heating with wood chips and solar collectors. Heat pump systems have somewhat higher carbon emissions, while electrical heating have significantly higher emissions. These differences in heating energy supply emissions can be seen more clearly from Figure 15, which shows the carbon emissions only for the heat energy supply options.

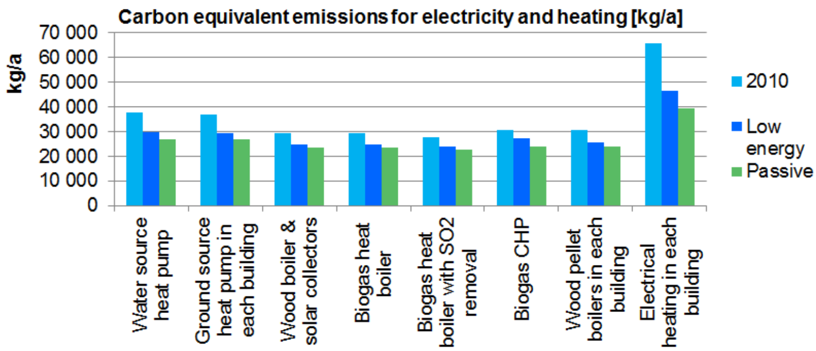


Figure 14. Annual carbon equivalent emissions from electricity and heating.

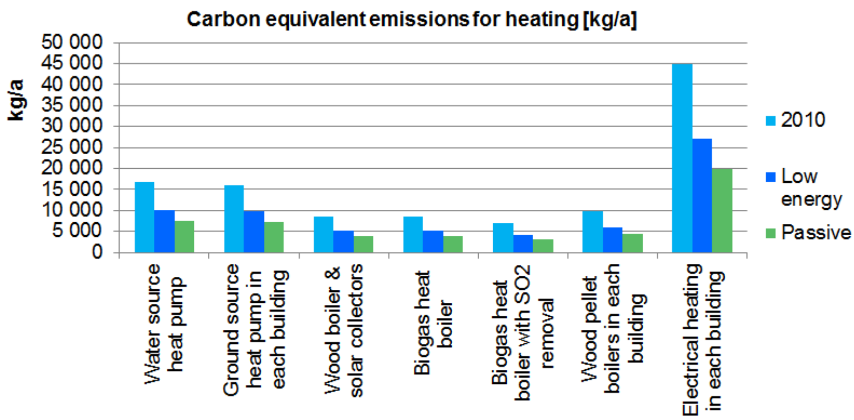


Figure 15. Carbon equivalent emissions from heat production.

Analysed SO_2 emissions are shown for electricity and heating supply in Figure 16 and for heating energy supply in Figure 17. Similarly, TOPP equivalent emissions are shown in Figure 18 and Figure 19. The small particulate emissions are shown in Figure 20 and Figure 21. This case showed the importance of assessing all the life cycle emissions, and not just the carbon emissions, which are usually the only focus point related to environmental sustainability.

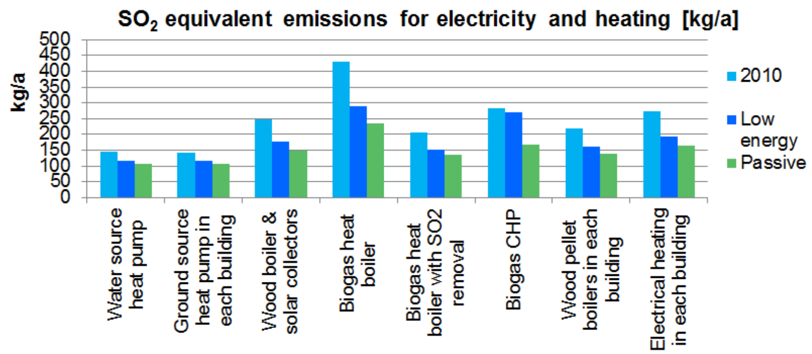


Figure 16. Annual SO_2 emissions for electricity and heating.

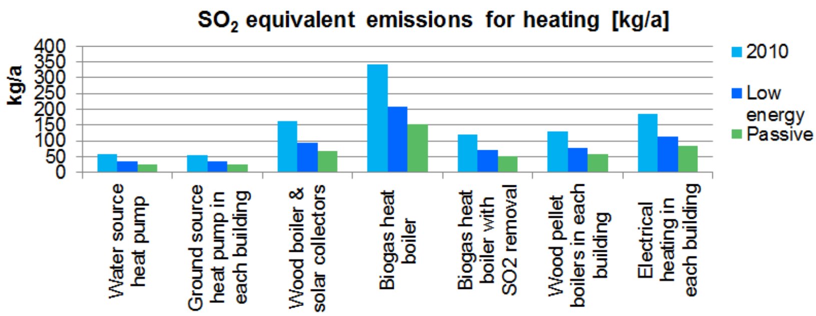


Figure 17. Annual SO_2 emissions for heating energy supply.

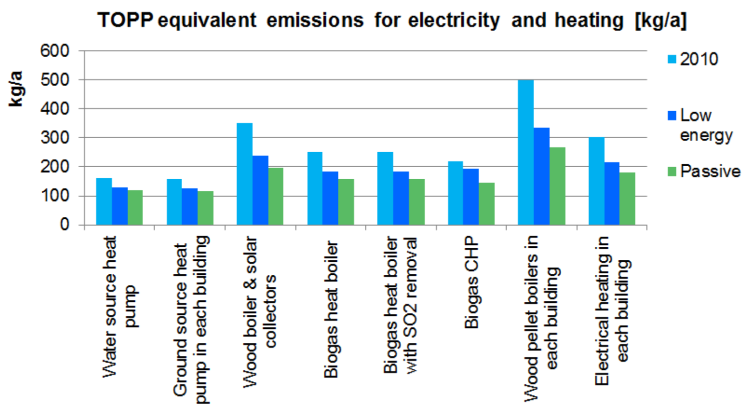


Figure 18. TOPP equivalent emissions for electricity and heating supply.

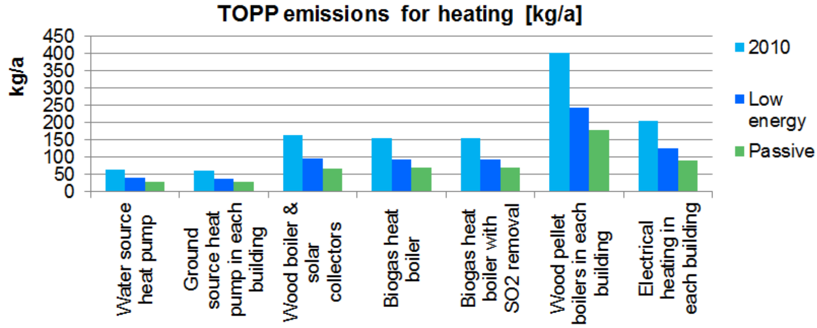


Figure 19. TOPP equivalent emissions for heating supply.

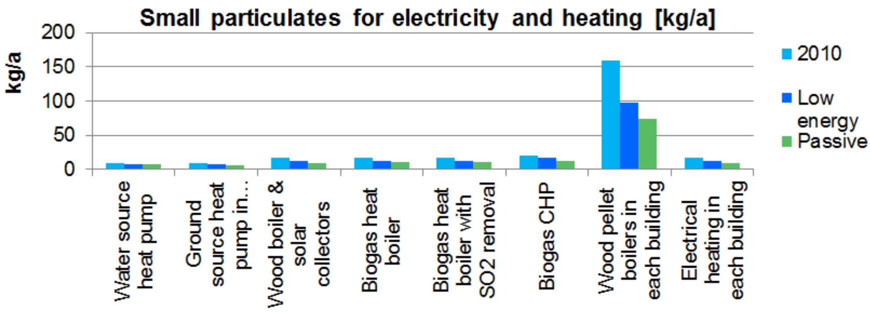


Figure 20. Small particulate emissions for electricity and heating supply.

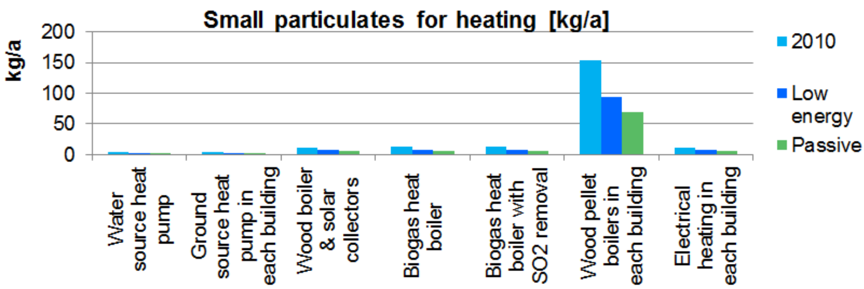


Figure 21. Small particulate emissions for heating supply.

4.2.2 Case 2: Säynätsalon kouluranta, Jyväskylä

The second case is a new residential area located in Säynätsalo in the City of Jyväskylä in central Finland. This case is introduced in Paper III, and is described in detail in a research report in Sepponen et al. [2010].

The draft plan of the area is shown in Figure 22, consisting of 12 large detached houses, 4 townhouses with 4 apartments in each, and optionally either of 40 small detached houses or 8 row houses with 5 apartments in each house.

Figure 22. Draft of the urban plan for Säynätsalon kouluranta area in Jyväskylä [Jyväskylä municipality, 2010].

The energy analysis used is mostly similar to case 1, but the district heating losses were analysed in more detail. Here, district heating losses are calculated for the estimated district heating network lengths based on the draft urban plan. The type of district heating pipelines was estimated to be DN25, for which average heating losses in Finland are 15.8 W/m [Koskelainen et al., 2006, p. 217]. This would mean that annual heat distribution losses for the district heating network would be approximately 0.138 MWh/m per year. Furthermore, it was assumed that, in the low energy and passive building scenarios, the district heating network would be designed to be operating more efficiently (as so-called "light district heating") with 20% reduced district heating losses compared to the usual BAU design [Hagström et al., 2009].

The district heating loss analysis is shown in Table 11. It shows a significant increase of the heat distribution losses from 25% in the BAU scenario to 38 % in the passive building scenario. This increase is due to a significant reduction in the total heat demand, as the heating demand is 56% less in the passive building scenario than in the BAU 2010 scenario. Another conclusion from the more detailed district heating loss analysis is that, when analysing quite low density neighbourhoods and smaller areas, such as in this case, the share of district heating losses can be significantly higher than the often used average Finnish district heating losses of 8–10%.

Table 11. District heating loss analysis in case 2 Säynätsalon kouluranta.

	BAU 2010	Low energy buildings	Passive buildings
Heat energy demand [MWh/a]	473	284	208
District heating losses [MWh/a]	160	128	128
Total district heating production [MWh/a]	633	412	336
Distribution losses from the production [%]	25	31	38

Another special question in this case analysis was to compare two draft urban plans from the energy perspective with the choice of planning either 40 small detached houses or 8 row houses with 5 apartments in each row house. The analysis showed as the main difference that, since row houses have relatively fewer external walls, their energy demand is 11–13 % lower than for the same size detached houses (Figure 23).

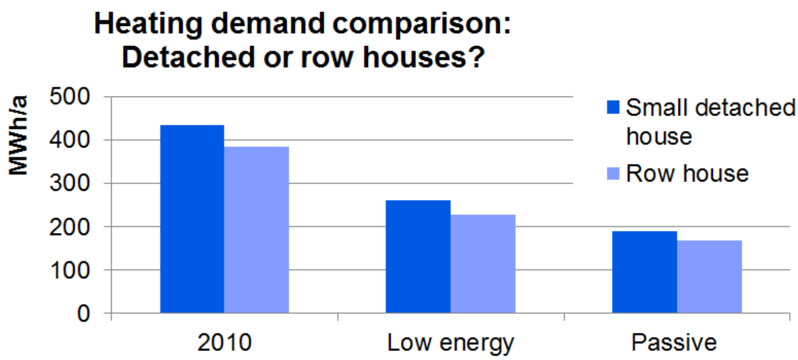


Figure 23. Comparison of heating demand for detached houses and row houses.

4.2.3 Case 3: Öijänniemi, Kannonkoski, Finland

The Municipality of Kannonkoski was planning a recreational area to Öijänniemi area with 26 vacation cottages with time shares (Figure 24). The area is located in central Finland. The vacation cottages were planned to be constructed from wood logs. The detailed energy analysis is reported in Sepponen et al. [2010], and it had the same approach as in cases 1 and 2.

Figure 24. Land use plan of the Öijänniemi recreational area in Kannonkoski. [Municipality of Kannonkoski, 2010]

The first special focal point in this case analysis was related to studying energy efficient Finnish-style wooden external wall construction options and their impacts on maximising the energy efficiency of houses. The energy demands of compared scenarios are shown in Figure 25.

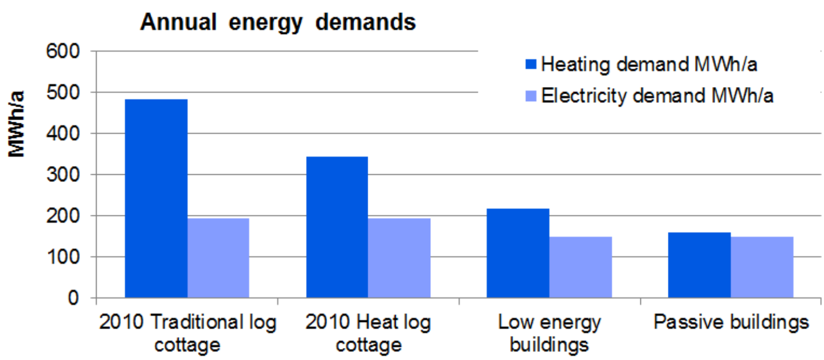


Figure 25. Annual energy demands in Öijänniemi vacation cottages.

Secondly, special focus was put on comparing the choice between electrical and wooden heated saunas in the vacation houses. Electrical saunas increase the total electricity demand of cottages significantly (Figure 26), and their carbon emissions are many times higher than for the wood-heated saunas (Figure 27, on the left side). However, wood-heated saunas produce significantly higher small particulate and TOPP emissions, affecting local air conditions (Figure 27, on the right side).

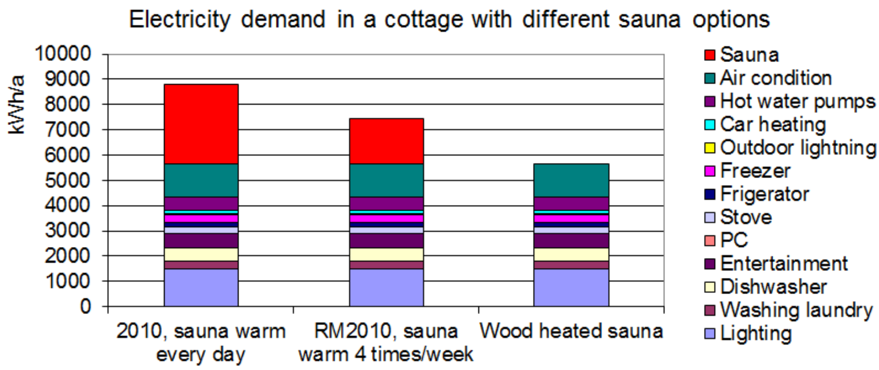
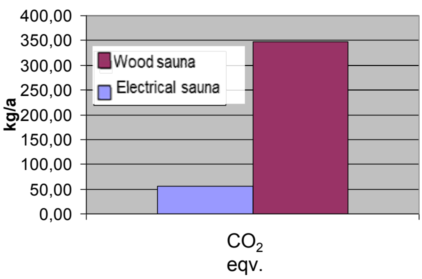


Figure 26. Comparison of sauna usage and its impact on the electricity demand in a cottage.



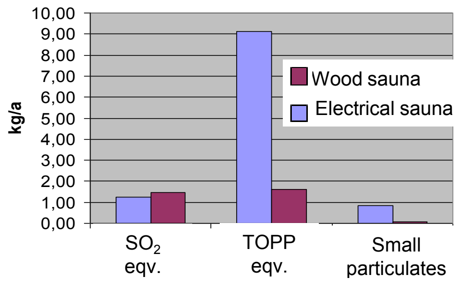


Figure 27. Comparison of life cycle emissions, carbon emissions on the left, and SO_2 equivalent, TOPP equivalent and small particulate emissions on the right.

4.2.4 Cases 4–6 in central Finland

Case 4 was **Kaistinmäki district in Petäjävesi**, Finland. This was a new residential area under planning, and it is located in a ground water area. The plan included 45 detached houses and 5 plots with combined residential and small industrial spaces, which were targeted at small and medium-sized entrepreneurs with work spaces, repairing facilities, etc. (Figure 28). In addition, 4 small plots were reserved for common services and spaces. The energy and emission calculations were done similarly to case 2 analysis, and in addition a short overview of off-grid energy solutions with available energy storage options was considered in Sepponen et al. [2010] and in Nystedt et al. [2012]. The energy analysis also included a local wind energy supply scenario.

Figure 28. Land use plan of the Kaistinmäki area [Hyyti, 2011].

Case 5 was **Könkkölä district in Jämsä**. The district plan consisted of 45 detached houses (39 small houses of 125 m^2 and 6 big houses of 220m^2) and 3 already existing, old buildings that were excluded from the analysis (Figure 29). The energy analysis followed the same approach as used in case 2, and it is reported in Paiho et al. [2013, p. 83 - 86] and in Sepponen et al. [2010]. The main focus in this case study was to compare two optional urban plan drafts for the area from the energy performance and emission viewpoints.

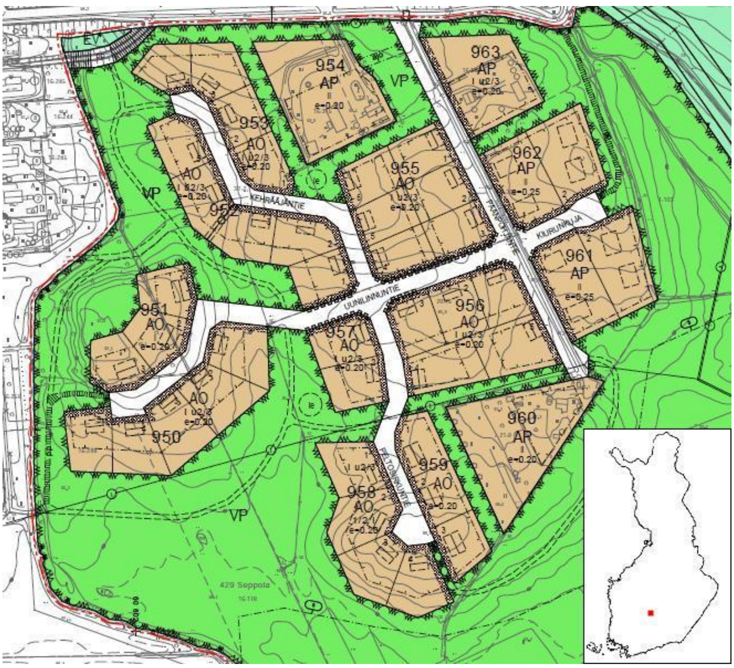


Figure 29. District plan of Könkkölä area in Jämsä. [modified from City of Jämsä, 2010].

In case 5, a district heating network already existed close to the case area, but it was not yet decided whether it would be expanded to the case area. The energy system options compared included: electrical heating, pellet boilers in buildings, ground source heat pumps (in each building or in groups of buildings), district heating plant, and solar thermal use with a seasonal storage. In the solar thermal scenario with seasonal storage, it was calculated that the total solar collector area required for providing the total heating energy needed was approximately 1100 m^2. Building-specific pellet boilers were ranked as the most efficient option, and second best option was a district heating boiler with wood chips [Paiho et al., 2013].

Case 6 was **Kyöpeli area in Multia** in central Finland. The Kyöpeli area was planned for 39 detached houses, 2 row houses, 4 small industrial plots and 1 service station (Figure 30). The energy analysis followed the approach used in cases 2 and 5 and it is reported in Sepponen et al. [2010]. The energy analysis also included a local wind energy supply scenario.

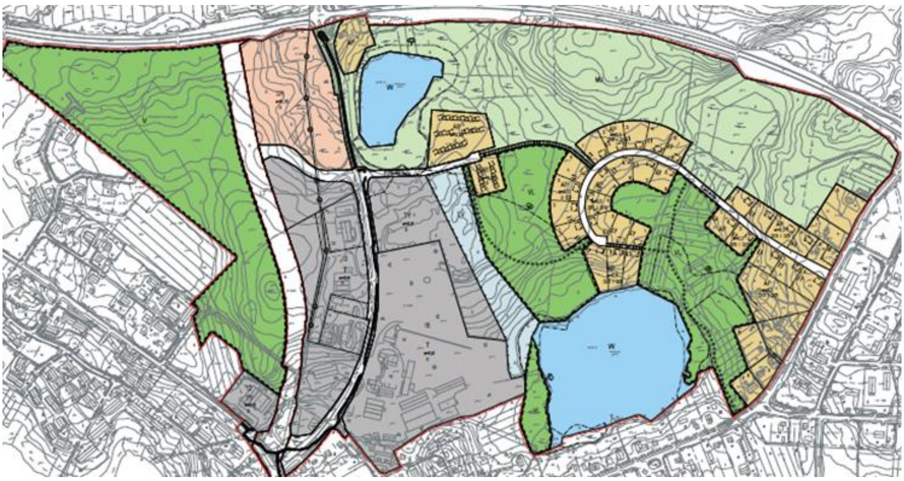


Figure 30. Plan draft of the Kyöpeli area in Multia [Seppä, 2010].

4.2.5 Case 7: Koukkuranta in Vuores, Tampere

The 7th case study was Koukkuranta neighbourhood in Vuores, Tampere in Finland. The detailed analysis is described in Paiho et al. [2013, pp. 87–91]. The land use plan was divided into two parts: a denser area in the south with apartment buildings and row houses, and a less dense detached house area in the northern part (Figure 31). The planned gross floor area was over 50 000 m^2, consisting of 40 detached houses, 110 apartments in residential housing corporations (in row-houses, semi-detached houses and detached houses), and 300 apartments in apartment houses.

Figure 31. Land use plan for the Koukkuranta in Vuores, Tampere [modified from: City of Tampere, 2011].

The buildings in Koukkuranta were assumed to be built as low energy buildings according to the sustainability and efficiency targets set for the Vuores development project. The length of the heat distribution network was calculated on the basis of the district plan. The existing district heating network was planned to be extended to the southern part of the Koukkujärvi, and possibly also the less dense northern part of the area. The carbon emissions of energy supply alternatives are shown in Figure 32 and small particulate emissions in Figure 33.

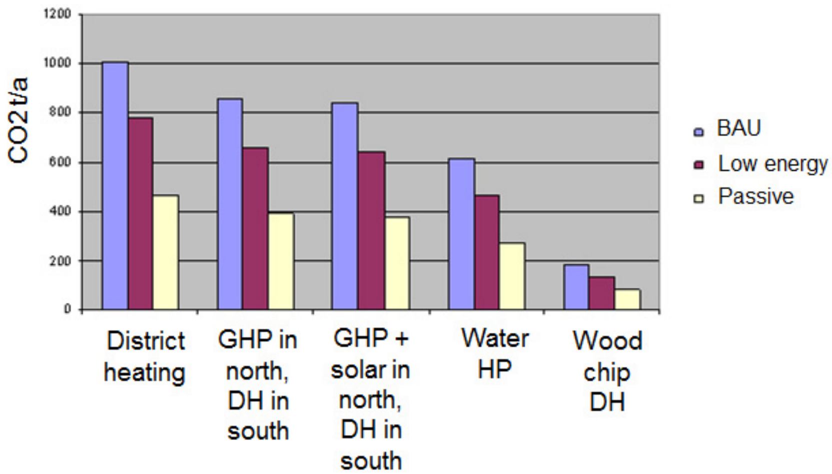


Figure 32. CO_2 equivalent emissions of heat supply in Vuores case.

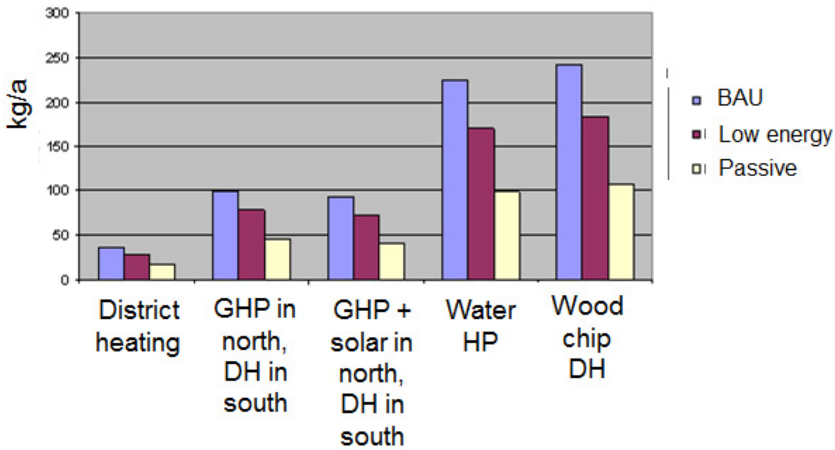


Figure 33. Small particulate emission of heat supply in Vuores case.

4.2.6 Case 8: Ecograd 1, St. Petersburg, Russia

Case 8, called Ecograd 1, was located close to the Peterhoff area in St. Petersburg in Russia. The area is located next to a local railway station, which strongly supports sustainable public transportation planning and easy commuting to other parts of the city. A draft of the land use plan is shown in Figure 34. The area was planned for 20,000 inhabitants with an average residential area of 30 m^2 per inhabitant, meaning in total 600 000 m^2 of residential buildings. The plan had five different building types:

dense, low and dense, detached houses and villas. The area is planned to be built denser the closer the train station is, which enables more people easier connections to the train. Also, local services are planned near the train station, which strengthens the sustainable transportation further and aims to reduce the need for using private cars, while also making the area more attractive. The analysis is presented in Nystedt and Sepponen [2011] and in more detail in Nystedt et al. [2010].

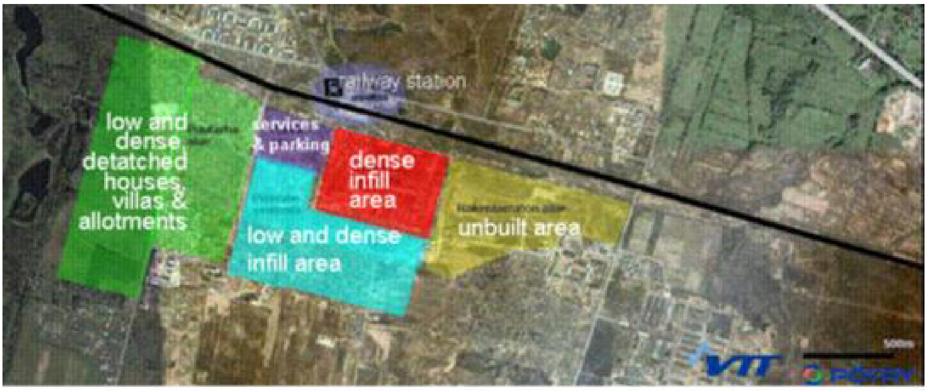


Figure 34. General plan for the Ecograd 1 area [Nystedt et al., 2010].

This energy analysis shared a similar approach as used in cases 1–6, but naturally the base data represented Russian building charasteristics. The energy demand was calculated in three scenarios: base case, low energy and passive building levels. Heat energy demand was reduced in the passive building case to 50% of the base case demand, mainly due to improvements reducing space heating demand. On the other hand, the demand reduction potential for hot domestic water and electricity use was more challenging, as they depend more on the habits of the inhabitants.

Energy production comparison included a highly advanced target with using 100 % renewable energy sources with as low emissions as possible. For this, ground heat pumps, solar panels and wind energy were considered. Other options studied included a combined heat and power production (CHP) plant fuelled with wood chips; or a CHP with biogas from wastes. The carbon emissions of these options are shown in Figure 35 compared to the current typical Russian energy supply from natural gas based district heating.

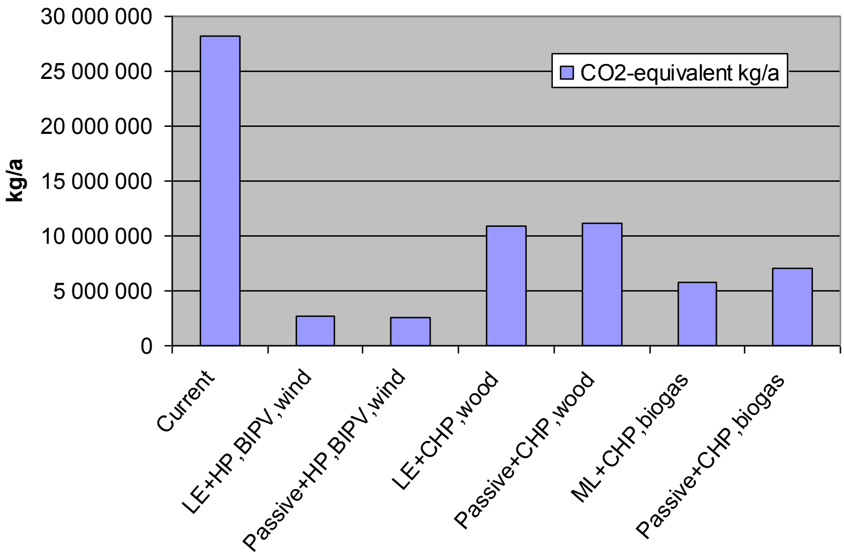


Figure 35. CO_2 equivalent emissions from different energy production options in the Ecograd 1 case. (LE = low energy buildings, Passive = Passive buildings, HP = heat pump, BIPV = building integrated solar panels, CHP, wood = CHP plant that uses woodchips, CHP, biogas =CHP plant that uses biogas). [Nystedt et al., 2010]

4.2.7 Case 9: Ecograd 2, St. Petersburg, Russia

The Ecograd 2 case is located to the southeast of downtown St. Petersburg, and its layout is shown in Figure 36. The area was planned for 11,500 residents with a total residential floor area of 350,000 m^2. In addition, common spaces have been reserved for a school, a day care centre, a health clinic, commercial services and a fire station.

Figure 36. Layout of the Ecograd 2 area. Low buildings in the centre are public services and commercial spaces [Nystedt et al., 2010].

In this case analysis, the focus was on comparing the current (base) situation to passive buildings (Figure 37). The energy supply scenarios compared options for 1) as low emissions as possible and 2) supply options without extra costs compared to the current situation, in which electricity is bought from the grid and district heating produced from natural gas. Again, life cycle emissions are compared for all energy demand and supply scenarios.

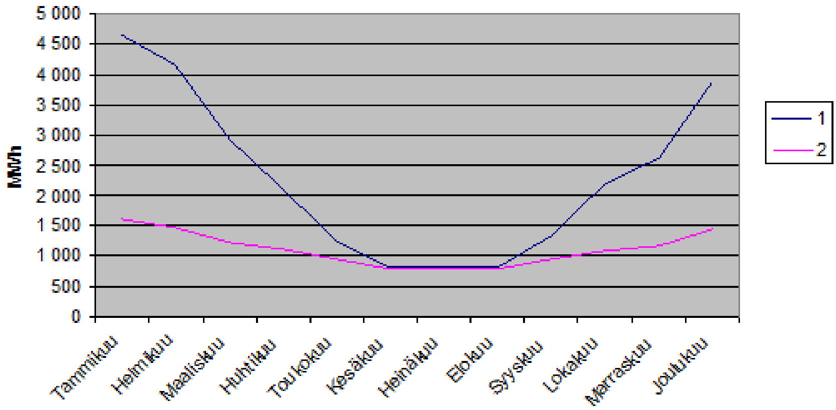


Figure 37. The annual energy demand of BAU (1) and passive (2) buildings for each month of the year in the case 9: Ecograd 2 [Nystedt et al., 2010].

4.2.8 Case 10: Ecograd 3, St. Petersburg, Russia

The Ecograd 3 case was called a PPP (public-private-partnership) case, and it is located on Vasiliyevsky Island in St. Petersburg. This area plan was for a residential area for 1,750 residents as a modern European style residential area targeted for international inhabitants. The area was planned be built on a raised waterfront, which makes the construction of underground facilities difficult. An illustration of the plan is given in Figure 38, with two building blocks. The block next to the waterfront consists of townhouses with two and four stores (3,840m^2 and 8,680m^2 per building) and the other building block consists of 16 store high-rise buildings (á 7,680 m^2) with apartments, offices and consumer service spaces.

Figure 38. Illustration of the PPP case plan in St. Petersburg. [Nystedt et al., 2010].

In this case the energy analysis compared three scenarios: base situation, low energy buildings and passive buildings. The annual carbon emissions are shown in Figure 39.

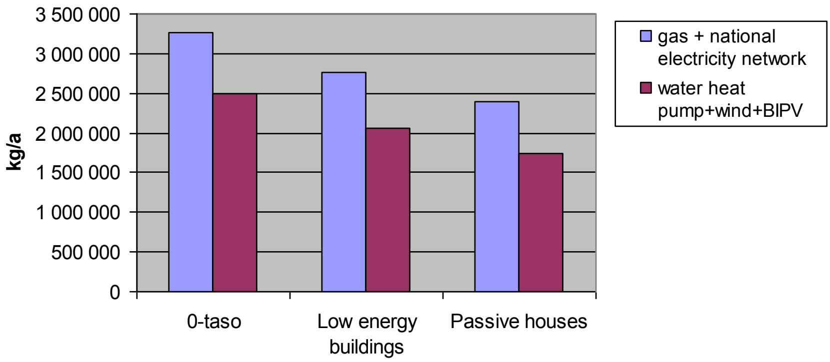


Figure 39. CO_2 equivalent emissions for the PPP case [Nystedt et al., 2010].

4.2.9 Case 11: 4th Microrayonof Zelenograd, Moscow, Russia

Case 11 is a typical, old Russian residential district in Moscow with apartment buildings built between 1966 and 1972. This area represents a typical Russian area with an urgent need for renovation and modernisation. The energy saving potentials of apartment buildings in residential districts in Moscow was studied in Paper I [Paiho et al., 2013], and this study was continued with energy and emission analyses of renovation scenarios in Paper II.

The energy analysis method used follows the same approach as in previous cases, but the base data and the scenarios were fitted to the Russian operation environment. The analysis compared four scenarios: current status, basic renovation, improved renovation and advanced renovation [Paiho et al., 2013]. The energy demands of these scenarios are shown in Figure 40.

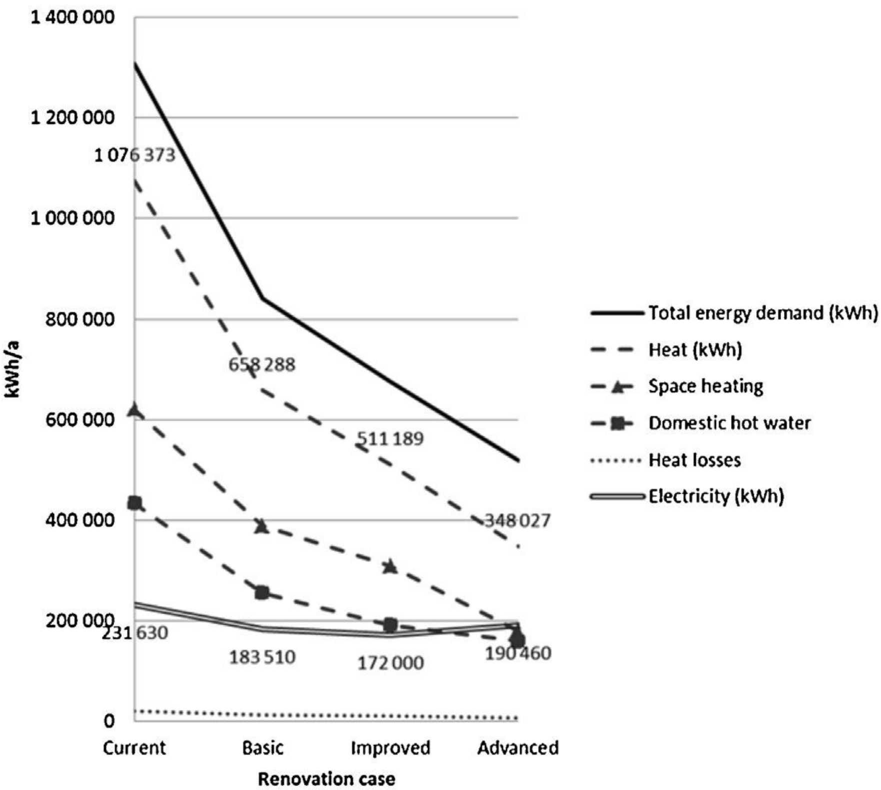
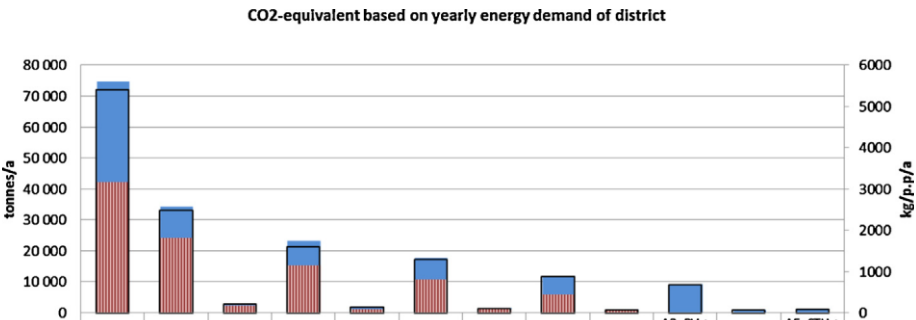


Figure 40. Energy demands of building renovation scenarios [Paiho et al., 2013].

It was concluded in Paper I [Paiho et al., 2013] that achieving a truly efficient energy solution in the Moscow district requires analysing the entire energy chain and how improvements should be made from the holistic system viewpoint. These were studied further in Paper II [Paiho et al., 2014] by comparing the energy demand and emissions of building energy renovation scenarios combined with the alternatives for modernising the energy supply system. The district level renovation concepts developed can be seen from Appendix B from Table 3. These district renovation concepts took into account buildings, energy production options, heat and electricity distribution systems, outdoor lighting, water purification and waste water collection and treatment, waste collection and treatment, as well as the links between energy system and urban planning, transportation and space use [Paiho et al., 2014]. This case analysis showed a significant energy and emission saving potential at the building level, and even higher saving potentials if a holistic approach were to be used to modernise the entire energy supply chain. The electricity savings varied from 24% to 34% and annual heating demand savings from 42% to 72%.

Paper II [Paiho et al., 2014] showed that emissions produced relate both to the efficiency of the energy utilisation and the energy source itself. As an example, a comparison of carbon emissions is shown in Figure 41, and similar calculations were also made for SO_2 and TOPP equivalent emissions and small particulates (in Appendix B Figures 3, 4 and 5). As concluded in Paper II [Paiho et al., 2014], the emissions analysis showed that the amounts of each emission type produced might depend on different factors. For instance, if fuel would be switched from natural to biogas, CO_2 and TOPP equivalent emissions would fall significantly. However, this fuel switch would result in twice the amount of produced SO_2 equivalent and small particulate emissions. The emission comparisons presented in Paiho et al. [2014] showed that there is no straightforward answer to choosing the best energy scenario, not even if only considering emission reductions. It seemed that the lowest polluting energy supply options were different when looking at CO_2 and TOPP equivalent emissions compared to looking at SO_2 equivalent and small particulate emissions. Hence, it is important to have a clear understanding of the objectives of targeted improvements in order to make the right decisions when selecting the most efficient improvement scenario [Paiho et al., 2014].



	Moscow ref.	Current Nat.	Current Bio	Basic Nat.	Basic Bio	Improved Nat.	Improved Bio	Advanced Nat.	Advanced Bio	A3: PV + GSHP + bought electricity	A4: PV + GSHP + WF	A5: STH + PV + GSHP + WF
Elec	32440.07	9913.87	725.61	7837.35	583.34	6878.03	510.90	6196.83	487.19	9026.98	683.26	653.18
Heat	42259.08	24296.02	2278.04	15328.07	1156.41	10863.04	1066.75	5848.27	701.74	282.01	282.01	385.42
kg/p.p	5407.89	2476.64	217.45	1592.22	140.62	1284.37	105.37	872.01	68.39	673.93	69.88	75.19

Figure 41. CO_2 equivalent emissions of the district energy supply options [Paiho et al., 2014].

4.2.10 Case 12: Vartiosaari, Helsinki

The twelfth case is an island in Eastern Helsinki with a total area of 82 hectares. The district is currently under planning with targets for building residential houses for 5,000–7,000 inhabitants with a total floor area of 300,000–350,000 m^2. Detailed district energy analysis and results are described in Paiho et al. [2015].

The Vartiosaari case analysis, research goals and methods used had several unique characteristics compared to the other cases analysed. Firstly, it compared the following two building models: 1) the 2012 building model based on current Finnish building regulations, and 2) SunZEB (solar-based zero energy buildings) concept developed by Shemeikka et al. [2015]. The SunZEB concept is one possible model that fulfils the impending nearly zero energy building requirements. In this concept, the basic idea is letting the sun to shine into the buildings. The comfortable indoor environment is maintained through summertime district cooling, which also recovers the excess heat with a heat pump and recycles the heat to be utilised elsewhere through district heating network.

Another unique aspect in the Vartiosaari analysis was that it focused purely on studying solar assisted district heating and cooling solutions at the district level combined with seasonal heat storages. Different options for integrating solar thermal supply with tank thermal energy storage and bore hole thermal energy storage were studied, and their impacts to energy self-sufficiency, and to CO_2, SO_2 and small particulate emissions were calculated.

4.3 Cases 13 and 14: Eriksnäs in Sipoo and Kivistö in Vantaa

The last two cases (13 and 14) were used to test the developed low carbon urban planning methodology. Both areas were typical Finnish urban areas located in the Helsinki metropolitan area. They represent different levels of the land use planning; Kivistö is a small new residential neighbourhood under development of a detailed plan, and Eriksnäs is a larger district, for which a master plan was being developed. The details of these cases is presented in Paper V. [Paper V]

Kivistö test area consisted of a detailed plan of a new small neighbourhood, and it was one of the first construction areas in a new Marja-Vantaa district under development in the city of Vantaa. It consisted of six residential blocks, a public service building and a car parking area. [Paper V]

Eriksnäs district was a part of the Sibbesborg master plan located in the municipality of Sipoo. It had already a few existing buildings and a strong need for infill construction and development of the area. This case was in the early drafting phase, and the developed Kurke tool was used during the urban planning, with using the preliminary information about the specifications for the urban plan. Erisknäs area consisted of small neighbourhoods with blocks of apartment buildings and office buildings and blocks of detached buildings. Real time smart metering was planned for the new buildings. The areal density of Kivistö neighbourhood was planned to be almost double as high as in the Case 2 plan in Eriksnäs. [Paper V]

4.4 Lessons from district energy analyses

Lessons and knowledge about performing district energy analyses are summarised in this section. As noted in Paper I [Paiho et al., 2013], the key questions of the district energy analysis are:

- How is the energy currently produced for buildings and districts?
- What are the most efficient ways to reduce energy consumption and how much of it can be reduced?
- What are the life cycle energy emissions and costs of different alternatives? (Cost analysis is excluded from this dissertation.)

4.4.1 Need for evaluating the actual impacts of design alternatives

As highlighted in Papers II and V, it is important to consider all the different stakeholders involved in the planning and operation of district energy systems. Besides required base data collection, the requirement analysis provided a solid base for identifying the key stakeholders and taking their varying targets and requirements into account. The checklists of the relevant questions for identifying the requirements of the district energy analysis are presented in Section 3.2 in Table 4.

In general, the interviews done for the requirement analysis revealed a wide variety of cities' strategies and high level sustainability goals, ranging from detailed action plans and emission reduction targets to imprecise thoughts on increasing sustainability, energy efficiency or eco efficiency. Even in the cases with the detailed level emission reduction targets, it was still typical that urban planners, cities' decision-makers, constructors and facility managers and energy company representatives did not have a clear idea of the practical actions required for actually achieving the targets. Similar findings were made also e.g. by Eicker et al. [2015], Zaron and Verones [2012], Sampaio et al. [2013], and Huang et al. [2015], supporting the identified need for developing tools for supporting the planning of energy efficient districts and the related decision-making for their energy solutions. Reaction to this need is further discussed in the next section 5, and the gap has been aimed to shorten by developing a framework and a tool for assessing energy performance and emission impacts of district energy systems.

4.4.2 Localised energy scenarios with the holistic approach

The value of district energy scenarios comes from showing the potential for energy and emissions savings, and inducing discussion about alternative energy solutions for districts. The district energy scenarios compared are often examples and leave a lot of details still open for the detailed energy system planning. Furthermore, these kinds of energy analyses also show the importance of a holistic approach. As concluded in Papers I [Paiho et al., 2013] and II [Paiho et al., 2014], the bigger energy and emissions saving potentials seem to be reached through synergy benefits when considering broader, district level measures, instead of focusing on single buildings.

The district energy scenarios need to be specified locally based on the available energy sources and the targets for the urban area development. This supports identifying the local advantages and possibilities. The case analysed showed that buildings and transportation are typically the biggest energy consumers in districts, while the share of waste and water management systems and street lighting is quite small. However, waste and water systems could bring new alternatives for available local energy sources, supporting their inclusion in the energy supply side analysis.

4.4.3 The different purposes of district energy analyses

The appropriate level of detail of district scenario analyses depends on the targets of the work. Quite general level scenario comparisons showing energy demands and environmental impacts of energy sources (as in cases 1–6 in the Jyväskylä region of Finland and cases 8–10 in St. Petersburg, Russia) managed to give guidance and knowledge for the decision makers and urban planners in the pre-planning phase of developing the land use plans. Cases 7 (Vuores, Tampere) and 12 (Vartiosaari, Helsinki) included more detailed analysis focal points with the aim of providing additional knowledge both for the land use planning and the actual designing of a district energy system. Case 11 (renovated area in Moscow) studied the potential savings at a very detailed level, and thereby gave strong scientific proof of the possibilities and benefits of energy renovations of Russian residential districts [Paiho et al., 2014].

5. District energy analysis framework and tool

Paper III presented an energy efficiency classification tool developed to support Finnish urban planning at a practical level. This tool was developed for estimating energy efficiency of the district based on buildings' energy class certifications. It offers a simple and fast means for the first pre-planning estimates with very few base information from the planned buildings. However, this approach considers only buildings, available energy sources are listed only on the level of renewable or non-renewable fuels, and there are a few options for the transportation planning. It seemed that there is still a gap in supporting energy efficient urban planning, and especially on assessing the environmental impacts of urban planning and district energy solution alternatives. This issue was addressed in Paper V, with a focus on developing a district energy analysis framework and a tool to support the energy efficient and sustainable district planning.

5.1 What an ideal urban energy plan would be like?

The development of the district energy analysis framework began by clarifying the needs and requirements for assessing energy efficiency and environmental impacts of urban planning related decisions [Paper V]. This was achieved through an expert survey for urban planners and other urban planning experts. There were 19 respondents (9 from the public and municipal sector and 10 from the private sector). The survey results indicated that urban planning experts felt that they had challenges in evaluating the effects of alternative design choices on the overall energy efficiency and carbon emissions of urban plans. [Paper V]

There is already a wide variety of different assessment tools, but still, the survey responses showed that Finnish urban planners would benefit from a practical approach to assess the energy efficiency and carbon impacts of urban plans in their everyday work [Paper V]. More specifically, there is a need for clear recommendations, easy-to-use tools and rapid ways of evaluating the urban plan alternatives.

Respondents were asked to describe their views on what an ideal energy plan would be like. They saw it as a holistic strategy for urban development with identification of the key issues affecting to the sustainability of the area [Paper V]. Furthermore, it should include an effective transportation system and the utilisation of the local energy sources with their usage potential and the emission impacts [Paper V]. The ideal urban plan requires a holistic approach and understanding what choices are significant and have the major effects on emissions (see Figure 42).

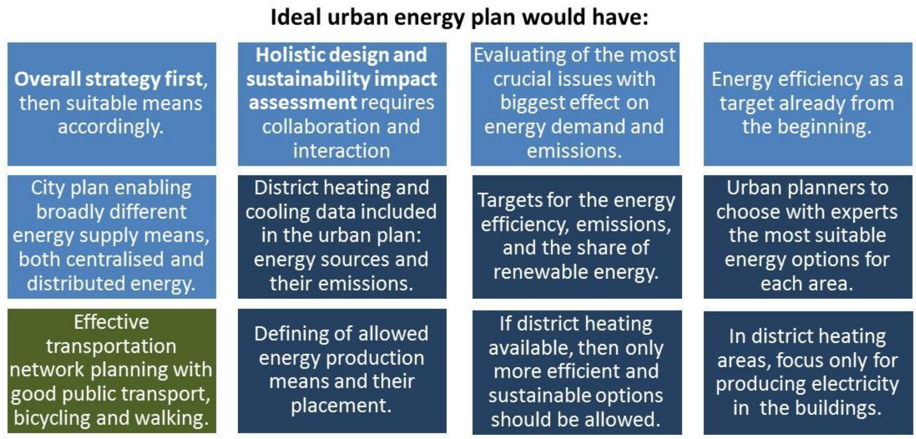


Figure 42. Requirements for an ideal urban energy plan [Paper V].

5.2 The framework and the tool for low carbon urban energy planning

To support urban planning, a district energy and emissions assessment methodology was developed for the pre-design phase of the urban planning in Paper V. This methodology and tool should be clear and easy to use, but it still needs to keep the appropriate level of detail to enable a sufficient comparison of the urban energy design alternatives. It aimed to provide information about the energy demand and alternative energy sources, and to show their environmental impacts for urban planners. In the end, this framework could increase urban planners' awareness of alternatives to the traditional designs [Paper V].

The energy analysis needed to include the key elements of district energy efficiency, which can be influenced in the land use planning. Similarly to Yamagata and Seya [2011], the entire energy chain of a district was considered, including energy demand in various types of buildings and passenger transportation, as well as different options for energy production, distribution and related energy losses [Paper V]. As a result, the energy analysis would show the energy demands (heating, cooling and electricity) of an urban plan, and the comparison of the CO_2 equivalent emissions for energy production and transportation system alternatives [Paper V]. The analysis process is shown in Figure 43, and the analysis steps are described in more detail in Appendix E (see Section 3.2). The analysis was implemented as an annual, statistical analysis. In the end, the analysis methodology was tested in two Finnish urban area areas.

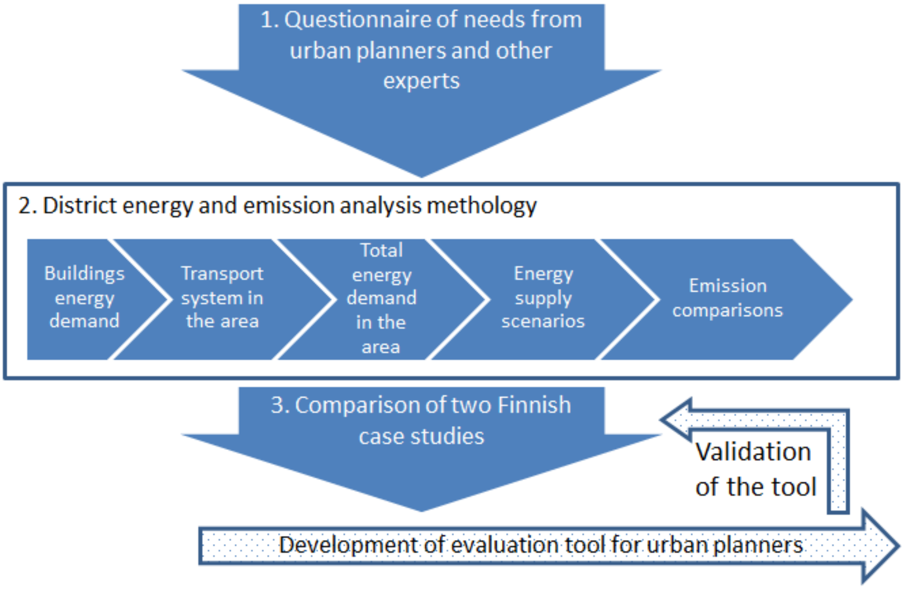


Figure 43. The process for analysing the district energy demand and carbon emissions. The following tool development is visualised with white arrows.

The framework and methodology presented above was utilised in the development of a spread-sheet-based district energy analysis tool called Kurke [Lahti, et al., 2012]. The tool can be used for assessing both new and existing districts. At first, the user needs to feed in base information about buildings in the area (Figure 44). As an assumption, the tool provides input places for 6 different types of buildings, which can e.g. be apartment buildings (for new and existing), single family houses (for new and existing), service buildings and/or office buildings. Next, the user needs to fill in the base data for the area (needed for the transport calculations) (Figure 45 and Figure 46). Thirdly, the user needs to fill in the base data related to energy sources and production (Figure 47).

1. Fill in the data needed for the calculation of energy consumption of the buildings in the case area

Building type (the name can be chan	New blocks of flats	Existing blocks of flats	New small houses	Existing small houses	Public services	Office buildings	"Small houses" include terraced houses, detached or semi-detatched houses.
Total floor area in the case area	690 180	0	52 400	0	80 000	20 000	floor square metres
Inhabitants/jobs, number	14 000	0	1 820	0	1 120	280	persons
average floor area/person	50	0	50	0	50	50	floor sq.m / person
Energy consumption: space heating	20	0	25	0	30	30	kWh/floor sq.m, a
Energy consumption: hot water	35	0	35	0	40	40	kWh/floor sq.m, a
Energy consumption: electricity	35	0	35	0	100	100	kWh/floor sq.m, a
Energy consumption: cooling	0	0	0	0		0	kWh/floor sq.m, a
Production of electricity on site	0	0	0	0	0	0	kWh/a
Production of heat on site	0	0	0	0	0	0	kWh/a

Mark *v* if there is a real-time electricity consumption monitoring service for the residents ☑

The option decreases the electricity consumption by: 8 % compared to business as usual (default value: 8 %[1])

Figure 44. Kurke tool input 1: data for buildings in the area.

2. Fill in the basic data of the case area

Amount of inhabitants and jobs* 17 220 persons

**Note! The amount is calculated from the table above, but you can also write the amount directly here.*

Average areal density in the case area:

within the district heating network * Medium

**Note! This calculation is for the rough estimation of heat transfer losses in the district hetating network only.*

comparison of different ways to determine the areal density

classification	description of density	plot density figure in town plans	HLT 2011-12 study areas (250*250 m grid)
very sparse	rural area	less than 0.1	alle 0.02
sparse	sprawl area	0.1-0.2	0.02-0.08
medium	terraced houses	0.2-0.3	0.08-0.16
dense	low-rise blocks of flats	0.3-0.4	0.16-0.32
very dense	high-rise of blocks of flats	more than 0.4	yli 0.32

Figure 45. Kurke tool input 2: base data of the area.

Location of case area (select the option that describes your case by marking ***v***; you can also use the attached thematic maps and the table above)[2]

Group of municipality (location and size of the municipality)	☑ Helsinki Metropolitan area	☐ big cities	☐ medium-sized cities	☐ small cities and towns	☐ other municipalities	☐ not known		
Size of the city region's central urban area	☑ Helsinki	☐ Tampere, Turku	☐ 80-200 000 inhab.	☐ 40-80 000 inhab.	☐ 25-40 000 inhab.	☐ 15-25 000 inhab.	☐ outside urban areas	☐ not known
Size of the urban area	☐ 200-2 999 inhabitants	☐ 3 000-9 999 inhabitants	☑ 10 000-19 999 inhabitants	☐ 20 000-49 999 inhabitants	☐ 50 000-99 999 inhabitants	☐ yli 100 000 inhabitants	☐ outside urban areas	☐ not known
Type of the locality	☐ urban area	☑ village area	☐ rural area	☐ not known				
Predominant building type	☐ blocks of flats	☐ small houses	☐ sparse small house area	☑ rural area	☐ not known			
Areal density (floor area/land area)	☐ below 0.1	☐ 0.1-0.2	☑ 0.2-0.3	☐ 0.3-0.4	☐ over 0.4	☐ not known		
Transport zone	☐ pedestrian zone	☑ local centrum	☐ fringe of central area	☐ area of frequent PT connections	☐ area of PT connections	☐ car zone	☐ outside transport zones	☐ not known
Distance to daily grocery	☐ 250 m	☑ 500 m	☐ 1 km	☐ 2 km	☐ 5 km	☐ outside service zones	☐ not known	
Distance to supermarket (>1000 sq.m selling floor space in the grocery)	☐ 500 m	☑ 1 km	☐ outside service zone	☐ not known				
Distance to hypermarket (>5000 sq.m selling floor space in the grocery)	☐ 500 m	☐ 1 km	☑ outside service zone	☐ not known				
Distance to elemenray school	☐ 250 m	☑ 500 m	☐ 1 km	☐ 2 km	☐ 3 km	☐ 5 km	☐ outside service zone	☐ not known
Distance to small green areas (> 1,5 ha)	☑ 0 m (within area)	☐ 100 m	☐ 200 m	☐ 300 m	☐ outside service zone	☐ not known		
Distance to large green areas (>20 ha)	☑ 0 m(=within area)	☐ 150 m	☐ 300 m	☐ 500 m	☐ 1 km	☐ outside service zone	☐ not known	
Distance to the most frequently used PT stop	☐ below 100m	☑ 100-300m	☐ 300-500m	☐ 500m-1km	☐ 1-3km	☐ 3-5km	☐ yli 5 km	☐ not known

In case the choice of locational alternatives above is difficult, you can instead select the option from the list below.

The case area is located in a specified city [Choose ▾]

The case area is located in a specified region/province [Choose ▾]

Figure 46. Kurke tool input 3: base data of the area for the transportation analysis.

4. Energy production alternatives

Heating	Electricity*	*Setting the energy production default values:*					
District heating	Grid power				* Grid power = electricity bought from the national grid		
Electric heating	Grid power						
Heat pump (house level)	Grid power	Coefficient Of Performance (COP)	2,5		* Assumed COP[3]: 2.5		
Heat pump (district level)	Grid power	Coefficient Of Performance (COP)	2,5				
Pellet boiler (house level)	Grid power	Transport distance of fuels	100	km	Note! Includes all transportation of pellets with CO_2e emission coefficient is [6]	0,02	kg CO_2e/km,MWh
District heating burning wood chips	Grid power	Transport distance of fuels	100	km	Note! Includes all transportation of wood chips with CO_2e emission coefficient is [6]	0,11	kg CO_2e/km,MWh
District heating	Solar power + grid	Total area of PV panels in the case area	30 000	sq.m	Equals to approximately 10 % of the annual electricity consumption being produced by PV.		
Solar heat + district heating	Grid power	Total area of solar heat panels in the case area	30 000	sq.m			
Solar heat + wood chip DH	Grid power	Total area of solar heat panels in the case area	30 000	sq.m			
District heating	Wind power + grid	Production of wind power	3 000	MWh/a	Production is 8,6 % of annual electricity consumption (approximately)*		

*In order to produce this, approximately 3 pieces of 1 MW wind power plants is required

NOTE: the production of wind power is totally dependant on local wind conditions.

CO_2-equivalent coefficients used in calculations:

Alternative CO_2-equivalent coefficients for electric heating and heat pumps [4]

Average electricity	☑	Average coefficient for grid power [5]	274	kg CO_2e/MWh for electric heating (average value in Finland during 2000–2007; allocation by benefit distribution method)
Wintertime + separate production units	☐	winter time: december-february, covering about 40 % of all heat production		
Electricity from separate production units	☐	Electricity from separate production units [5]	891	kg CO_2e/MWh

Other emission coefficients:

(Note: assumed coefficients during whole life-cycle)

Energy production	CO_2-equivalent emissions kg/MWh		
District heating [5]	217	kg/MWh (using benefit distribution method, average level in Finland during 2000–2007)	
District cooling [7]	70	kg/MWh (Note: The default value is Helsinki average, based on local district cooling technology [8])	
Heat pump equipment	9	kg/MWh	*assumption to renewables is 0 kg/MWh for the sake of uniformity in calculation because the emission data of district heating and electricity are NOT calculated with LCA principles.*
Pellet boiler (district heating)	9	kg/MWh	
Wood chip boiler (district heating)	29	kg/MWh	
PV panels	110	kg/MWh	
Solar heat panels	24	kg/MWh	
Wind power	58	kg/MWh	

Figure 47. Kurke tool input 4: energy production alternatives.

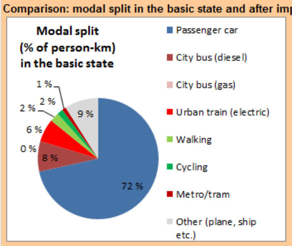
As a result, the Kurke tool gives a comparison of transport demand in the area and the comparison of the modal split in a business-as-usual situation and with improved transport planning options (Figure 48). The energy demands of the districts are visualised (Figure 49), and the comparison of carbon emissions per person are given in Figure 50.

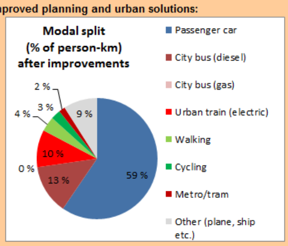
3. Transportation mileage in the case area (trips to work, shops, schools, other services and occupational trips, person-km/a)[2] — **Impact of planning and design solutions**

Mode of transport	Mileage (person-km/day)				Basic state %	Changed state %
Passenger car	30,0 person-km/day	equalling	10937	person-km/a	71,5	59,5
City bus (diesel)	3,4 person-km/day	equalling	1244	person-km/a	8,1	13,2
City bus (gas)	0,0 person-km/day	equalling	0	person-km/a	0,0	0,0
Urban train (electric)	2,6 person-km/day	equalling	942	person-km/a	6,2	10,0
Walking	1,0 person-km/day	equalling	377	person-km/a	2,5	4,0
Cycling	0,7 person-km/day	equalling	245	person-km/a	1,6	2,6
Metro/tram	0,4 person-km/day	equalling	158	person-km/a	1,0	1,7
Other (plane, ship etc.)	3,8 person-km/day	equalling	1385	person-km/a	9,1	9,1
Total	41,9 person-km/day	equalling	15287	person-km/a	100	100

Urban planning and desing solutions decrasing the demand for private cars:		Impact on modal split (%-units):
Separate cycling routes and good cycling parking facilities	Good	Share of cycling +2%
Centralized car parking facilities	None	Share of passenger cars 0%
Urban train station within the case area	400 - 600 m	Share of urban trains +2%
Grocery, day care centre and elemntary school within 400 m	All within 400 m	Share of walking and cycling +4%
frequent and high-quality bus and tram lines	Good	Share of public transport +2%
dense high-quality and safe walking routes	Good	Share of walking +2%

Comparison: modal split in the basic state and after improved planning and urban solutions:





Specific emissions, average 2011-12

	g CO_2e/pers
Passenger cars	98
City buses, 18 passengers/80 seats, diesel	59
City buses, 18 passengers/80 seats, natural gas	68
Urban trains, electric, 65 passengers/184 seats	22
Tram (esitimated)	22
Fast tram (esitimated)	22
Metro (esitimated)	22
Walking (esitimated)	9
Cycling, skiing, Nordic pushing sledge etc. (esiti	4

Figure 48. Comparison of transport planning options from the Kurke tool.

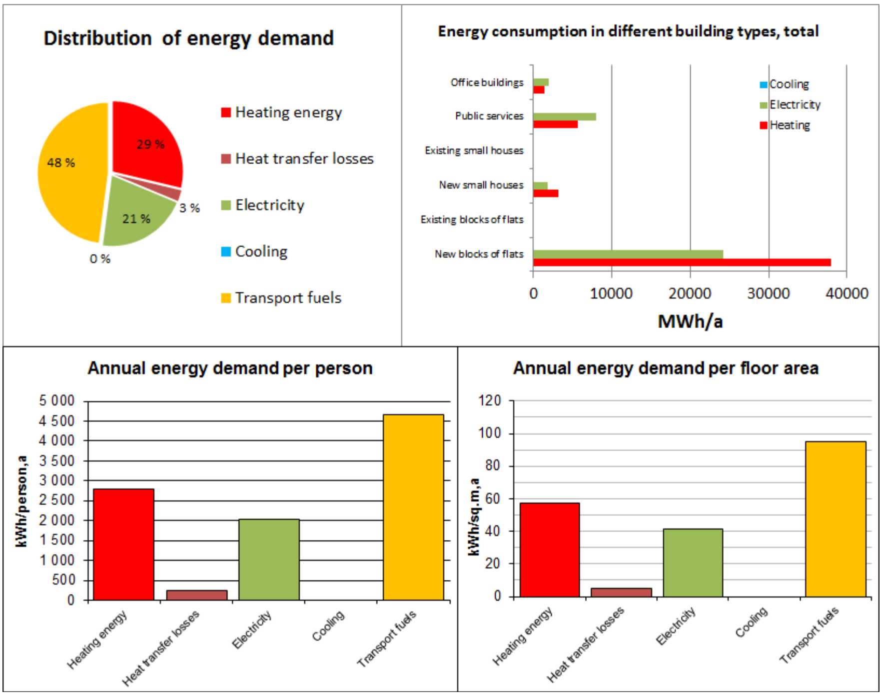


Figure 49. Kurke tool results: visualised energy demands of the district.

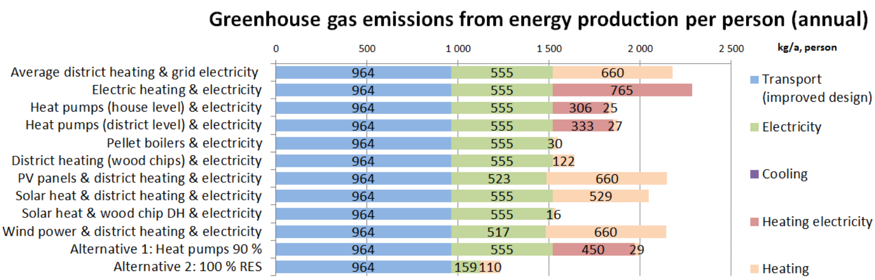


Figure 50. An example of Kurke tool results: Comparison of carbon emissions per person.

5.3 Testing of the framework and tool in Kivistö and Eriksnäs cases

The methodology was tested in two Finnish urban case areas with residential and mixed uses. The figures from the Kurke tool given in the previous chapter were taken from the Eriksnäs (Sipoo, Finland) case analysis. These analyses and their results are showed and discussed in Paper V.

The analysis results in the Kivistö area in Vantaa showed a potential to reduce the carbon emissions of transportation 20% with improved planning choices. Improving the energy efficiency of buildings could reduce carbon emissions from heating up to 24% and from electricity around 3%. It seemed that urban planning has better possibilities to reduce heating and cooling energy demand, while electricity demand is more dependent on the behaviour of users, and its reduction via city planning means is much more challenging. In total, the carbon reduction potential achieved with urban planning decisions varied from 4% to 49%, depending on the energy source [Paper V]. These results indicate the significant potential of urban planning-related choices in reducing carbon emissions.

In addition to making the case study calculations with the Kurke tool, the testing phase included also collecting of feedback from the urban planners. Especially interesting was to get feedback from the urban planners testing the tool in practise. Particularly, the transportation assessment part of the tool was considered to be highly useful when drafting urban plans. In general, urban planners gave positive feedback from both the level of the detail in the tool and the visualisation of results [Paper V]. It seemed that the Kurke tool raised interest to study new alternatives for business-as-usual energy sources and solutions.

5.4 Assumptions and limitations of the district energy analysis

The district energy analyses in this dissertation focused mainly on assessing the annual energy performance of districts. The annual level was considered to be suitable for providing fast and easy-to-understand analysis results to support the urban planning. The district energy analysis framework and tool called Kurke (presented in Section 5 and in Paper V], is built on an assumption that energy demand can be balanced by an external electricity grid.

As discussed in Paper V, the ultimate goal of this research was to develop a district energy analysis framework, which considers typical energy supply characteristics in Finland. These characteristics included the large share of district heating and CHP production, and the good availability of biomass based fuels. Regarding the energy demand of transportation, typical Finnish people use private cars a lot. One of the additional values of Kurke district energy analysis was to inspire urban planners and decision makers to raise discussion about alternative options for replacing the need for private cars with other more sustainable transportation modes in urban areas [Paper V].

District heating losses are traditionally calculated based on an assumption that they are either the same as the average heat distribution losses in Finland (8–10 %), or based on average heat distribution losses of city's district heating system, as e.g. in Pesola et al. [2011]. According to Fang and Lahdelma [2014], the heat distribution losses can vary from 10 to 20 % in small networks and around 4–10% in large networks. Similar variations were also seen in the case study analyses in this dissertation. The case study analyses showed a significant variation of heat distribution losses of district heating networks, with losses ranging from 4 to 25%. The developed Kurke district energy analysis tool [Paper V] included a district heating loss assessment method, which is based on the density of the district, the density of the heat demand and average district heating losses in different types of districts in Finland. As discussed in Paper V, one potential error source in the Kurke analysis framework might be that in real life, the heat distribution losses can vary from this estimation among others due to different designs of district heating systems. But still, the proposed estimation seems to give more realistic results than by using average heat distribution loss values instead. The developed method for calculating the district heating losses was considered to be an appropriate level of detail, as the target was to provide a practical and fast district energy analysis methodology to support urban planners, who do not have specific knowledge about energy systems and energy efficiency measures [Paper V].

It needs to be also noted that both the case studies described and the Kurke tool [Hukkalainen et al., 2016] have limited capabilities to truly assess the wind energy production potential in detail. They show an estimated potential magnitude of the wind energy supply, which is assessed based on the Finnish Wind Atlas web tool [2009]. In practice, wind energy supply is highly dependent on the local wind conditions.

In contrast to many of the case studies described in Section 4 (such as cases 1–6 and 8–12), the Kurke district energy analysis framework and tool [Paper V] considers only carbon emissions. The Kurke tool does not take into account other emissions to air, such as SO_2 equivalent, TOPP equivalent emissions and small particulates, which might limit its usefulness in some case areas, especially in those megacities that are struggling with poor local air quality.

Some of the case studies presented in Section 4 (e.g. case 12 in Vartiosaari, Helsinki) considered also more detailed energy system with the goal to give base information for the energy system planning at the later phase. In reality, buildings energy demand varies seasonally, daily, hourly and during shorter time steps. These are relevant questions in the detailed energy system design of districts, and their importance is increasing in the near future with the roll-out of energy matching and balancing solutions. This kind of detailed energy matching research is excluded from this research, as the main research question was to support urban planning and to increase urban planners' basic level understanding of the magnitude of energy solutions for sustainable and low carbon districts [Paper V].

5.5 Maximising the value of the district energy analysis

The value of utilising the district energy analysis depends strongly on how the results are communicated to the relevant stakeholders and how they are utilised in the urban planning and development and in the related decision making. At their best, district energy analyses are done iteratively during the progressing planning process and to show to urban planners the effects of their decision choices. They could also provide sufficient base information for the decision makers regarding the decisions about the land use and urban development decisions in the city. Such district energy analyses, as studied in this dissertation, can bring new alternatives for traditional design and show examples of means for implementing the cities' high level strategy goals for energy saving and emission reduction.

The energy analysis results could also encourage different stakeholders to develop a shared vision and concrete goals, which van der Schoor and Scholtens [2015] considered to be an important starting point for realising sustainable energy initiatives. However, these require clear interpretation and communication of the results, and open discussion among key stakeholders effecting to the energy efficiency of the district. It can vary case by case, who are these key stakeholders that should be involved in the discussion, but often they include at least local energy company and the municipality (e.g. urban planners and decision makers). The involvement of end users could bring additional benefits, and e.g. the potential roles of energy service providers could be considered.

5.5.1 The right metrics for the right stakeholders

As noted in Paper V, when discussing the district analysis results with urban planners, decision-makers and other stakeholders, the choice of metrics used in the communication matters. The selection of key performance indicators (KPIs) to present the analysis results can have a significant impact on the understanding and interpreting the results. The visualisation of the right metrics for the right stakeholders matters also.

In this dissertation, the focus has been on comparing the impacts of design alternatives in a single case area, with the final aim to plan each district as energy efficient and sustainable as possible. Energy demand for the entire district can be valuable information for the municipality and the energy utility, whereas for the benchmarking purposes and comparison of different areas, the metrics per person and/or per building floor area are better [Paper V].

The choice of used metrics depends on the targeted audience. Experts and engineers in the energy companies are used to discussing directly about energy values (e.g. MWh/a) for entire districts, whereas metrics per building floor area are traditional and widely used in the building projects. Often, facility managers might be more interested about comparable metrics, such as kWh/m^2/a. However, in this the limitation is that the effect of the size of building spaces and apartments is neglected. In practise, this means that if used values are dependent on the building floor area, it does not matter how small or big the apartments are. This could lead to a conclusion that low density apartments would have lower energy consumptions and carbon emissions, which would not necessarily support efficient space use [Paper V].

In public communication, values per person might be easiest to understand, as they give a better perspective for public audience. But here the challenge can be to know, what this person is – are they a resident, user, worker, or visitor to the district? And instead of discussing about energy demands directly, it might be clearer to focus on carbon emissions, or costs.

The energy analysis could be further improved to show the economic impacts, e.g. savings in energy bills. However, the economic impact analysis has challenges in assuring the accurate and up-to-date cost information, which tends to vary case-by-case [Paper V]. This is the reason why cost analysis has been excluded from the district energy analysis and tool development in this dissertation.

6. Business and operation concepts for district energy systems

Sepponen and Tommis [2013] identified a clear message from the municipality representatives that, besides developing ICT innovations and solutions for smart energy systems, emphasis should also be put to economic related challenges. Municipalities often face challenges in finding financing for energy efficiency measures and related ICT and other investments. Especially municipalities needed support in understanding the costs and benefits of solutions described with return of investment (ROI) of solutions, and concerns were raised about long pay back times. During the interviews, one municipality official stated that "it is hard to convince people that energy efficiency measures will generate revenues in the future, and pay back investment costs". These comments further clarified the importance of the need for new business, operation and financing models for district energy systems and related energy efficiency measures.

Paper II also concluded that the business models for modernising district energy solutions need to be studied further, including stakeholders' potential benefits and the incentives for realising energy efficiency improvements and renovations.

6.1 Stakeholders' requirements and attitudes

As presented in Paper IV, understanding stakeholders' needs, goals and roles in district energy business is a prerequisite for developing business, operation and service concepts. Stakeholders influencing the district energy business are mapped in Figure 51. End users and energy service providers were the key stakeholders identified, as they are running the practical actions.

The main actors' roles are described in Table 12. The identified needs for the main stakeholders are [Paper IV]:

- End users: reduction of energy bill, reduction of energy consumption, improvement of energy efficiency, reliability and dependability.
- Energy network operators: balancing the network and the energy load.
- Energy retailers: reduction of imbalance (difference between predicted use and real use), and optimisation of energy trade.
- Project developers and investors: power peak shaving to limit maximum power and therefore reduce the investment cost of the grid.
- Society and environment: reduction of CO_2 emissions, reduction of energy consumption, improvement of energy efficiency, maximising use of (local) renewable energy production.

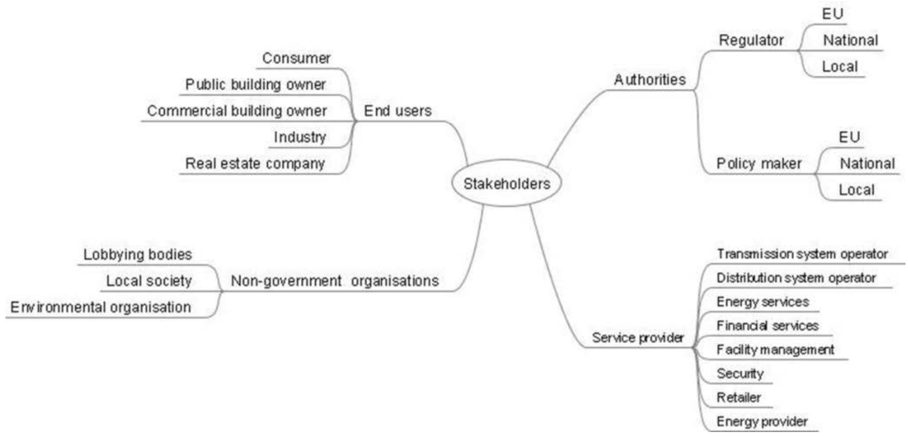


Figure 51. Stakeholders of district energy systems [Paper IV].

Table 12. Actors' roles in the energy market [Paper IV].

Actor	Role
Consumer	To consume energy, buys energy from energy retailer
Producer	To produce energy, sells energy to energy retailer
Prosumer[1]	To consume and produce energy, buys energy from an energy retailer.
Energy retailer	To buy and sell energy. Since a retailer cannot trade on the power exchange market, the retailer buys energy from a BRP. The retailer also pays fees to the BRP to cover imbalance risks.
BRP (Balancing Responsible Party)	To trade on the power exchange market on behalf of members of its portfolio, among energy retailers. BRP's that are out of balance are charged costs by the TSO. A BRP may have own power plants or trade energy on behalf of power generation parties.
DSO (Distribution System Operator)	Is responsible for the distribution of electricity, i.e. reliable and efficient operation of medium to low-voltage distribution systems. To prevent overcapacity on (parts of) the grid, the DSO is interested in peak shaving.
TSO (Transmission System Operator)	Is responsible for the transmission of electricity i.e. reliable and efficient operation of high and very-high voltage transmission systems.

[1] Energy consumer and/or producer

The starting point for developing new business and operation concepts for district energy systems was based on identifying market needs and current situation of the business models for district level energy services, as presented in Heimonen et al. [2012] and in Virtanen et al. [2014]. These publications identified, what kind of new services end users need now and in the future, what kind of services are expected from a service provider and what they are currently offering or willing to offer in the future. The results indicated a growing interest in smart energy systems and services on the part of both end users and service providers [Virtanen et al., 2014].

End users are interested in having green energy (produced by renewables, environmentally friendly, produced ecologically) [Heimonen et al., 2012]. However, the energy price is still a significant issue, and end users were either not willing to pay any extra for it or were willing to pay only a small additional price for green energy (typically less than 10% extra price). End users were also interested in the options of having their own local energy production and smart metering, which would show the energy consumption and costs in their own household [Heimonen et al., 2012]. End users noted that they would likely use smart energy management services for optimising their energy consumption and costs. Furthermore, end users were interested in buying pools and demand side management pools, while the service providers were willing to offer energy efficiency services (e.g. ESCO services), bundled energy services (e.g. heat/cool and electricity) and services minimising energy consumption and costs [Paper IV].

As reported in Heimonen et al. [2012] and in Virtanen et al. [2014], web survey respondents considered energy suppliers and distribution system operations to be suitable investors for the required systems, but the role of public sector was also raised. Additionally, the cost-benefit-based cost allocation method was proposed for sharing the system investment costs. According to the survey, the potentially best future energy service would be bundled energy services, and services for demand-side management and controlling energy costs [Virtanen et al., 2014]. According to a stakeholder survey [Virtanen et al., 2014], the biggest barrier to a smart energy district was the reluctance of existing energy sector players to change the conventional business models, but the lack of experience and knowledge about smart systems also hindered the development. Responses reflected a need for new business and service models that can fulfil stakeholders' needs related to district energy markets. [Virtanen et al., 2014]

6.2 Key performance indicators for measuring the viability of different business concepts in different cases

Paper IV showed how the performance of the business and service models can be measured in key performance indicators (KPIs). Potential KPIs were identified and classified into three categories: environmental, economic and service level indicators (Table 13). For each business case, the stakeholders need to select a suitable set of KPI's to measure the viability of the business model based on the objectives and needs of the organisation at a given time [Paper IV].

Table 13. Environmental, economic and service level key performance indicators for measuring the performance of business and service models [Paper IV].

Environmental KPIs	**Finance and business KPIs**	**Service level agreement KPIs**
(Average) primary energy consumption	Total energy purchased / sold	Delivery precision
Total energy (power, heating, cooling, fuels) generated	Profitability for the different stakeholders involved	Response time (for a service request)
Total renewable energy generated	Total turn-over (of energy trading i.e. purchased/sold energy and services)	Mean time between failure (time to repair)
Total energy stored	Total profitability	Reliability of energy provision
Total on-site produced renewable energy	Total energy costs	Security of energy provision
Energy saved due to conservation & efficiency improvements and changes to renewable energy production	Cash flow return on investments (e.g. net present value (NPV), Internal rate of return (IRR), and Return on investment (ROI))	
Total greenhouse gas (GHG) emissions	Total assets	
Other emissions, such as SO_2 equivalent, small particles, etc.	Sales per service	
GHG emissions saved (due to conservation & efficiency improvements and changes to renewable energy generation)	Profit per service	
	Total investments / capital expenditure	
	Total current liabilities (e.g. service contracts, leasing contract etc.)	
	Number of customers / service contracts	
	Customer satisfaction / reclamations	

6.3 The cookbook – a collection of business concepts for district energy services

As described in Paper IV, a set of new potential business concepts was developed for districts' smart energy solutions with a maximised use of renewable energy. These concepts were targeted for different actors with varying business ideas related to optimised district energy services, operation and business. The concepts were developed utilising a method modified from the Osterwalder approach [Osterwalder and Pigneur, 2010] taking into account the most crucial elements related to the stakeholders' needs related to the energy demand and supply. The concepts were kept simple and focused on one stakeholder at a time, which significantly improved their clarity and enabled their further integration into energy analysis and simulation. [Paper IV]

The business concepts were presented in a cookbook form, as a set of recipes for business and service concepts with descriptions of key ideas and interactions required between the main stakeholders. In addition, the offering and value proposition of the model is given, describing the roles of the main stakeholders (seller and buyer). In addition, the earnings and revenue model is presented and key performance indicators for measuring the success of the model were proposed. The evaluation of the costs and benefits was a key element. In total, 13 business concept elements for district energy systems were identified [Paper IV]:

Business concepts for offering energy demand and supply flexibility (1–5):

1. Flexibility for the energy retailer's portfolio management.
2. Flexibility enabling maximised utilisation of locally produced energy.
3. Flexibility for local network management enabling maximised renewable energy supply.
4. Flexibility in balancing services to the balancing responsible party and transmission system operator.
5. Flexibility for local balancing at district level.

6. Co-operative ownership of district heating network (6).

Business concepts for energy service providers (7–9):

7. Energy broker buying and selling energy.
8. Flexible energy tariffs for (residential) consumers.
9. ESCO minimising customers' energy bills and optimising energy use.

Business concepts for energy producers and energy companies (10, 11):

10. Heat storage utilised in district heating and/or cooling.
11. Flexibility in electricity network by heat pump to avoid peak power.

Business concepts for new roles (12, 13):

12. Heat recovery of excess heat utilised in district heating and cooling.
13. Prosumer selling self-produced energy.

As described in Paper IV, the elements of the business concepts can be combined into more specifically focused and broader business models, service offerings and business networks [Paper IV]. When developing a specific district energy business case, the selection of the set of suitable business concepts depends on the targets for the benefits sought and value captured in the case. Table 14 presents the indicative values that main stakeholders could capture or expect related to different business concepts.

Table 14. Expected benefits and value for different stakeholders by using the business concept elements. Numbers in the table refer to business concepts mentioned above. [Paper IV]

	Stakeholders	Retailer	Broker	Producer of RE	Distribution system operator	Balancing responsible party	Transmission system operator	Local balancing party	Consumer	Prosumer	Producer	Energy storage owner	Excess heat owner	Heat service provider	ESCO	Society
Value to capture	Energy balancing management	1, 10, 12	1			4	4									
	Management of selling and buying	1, 10, 12	1													
	Flexibility / demand response services	1, 10, 12	1	2	3	4	4	5								
	Energy cost savings	8, 10, 12							1-6, 8, 11	1-6, 8, 13						
	Good price for energy	8, 10, 12		2						1-6, 8, 13	1-6, 8	10	12	6, 11	9	
	Use of local energy															2,5
	Easy energy services								7,9	7	7	7				
	Lower emissions															1-13

Business concept elements:
1. Flexibility for the energy retailer's portfolio management.
2. Flexibility enabling max. use of locally produced energy.
3. Flexibility for local network management enabling max. RES
4. Flexibility in balancing services to the balancing responsible party and transmission system operator.
5. Flexibility for local balancing at district level.
6. Co-operative ownership of district heating network .
7. Energy broker buying and selling energy.
8. Flexible energy tariffs for consumers.
9. ESCO minimising bills and optimising energy use.
10. Heat storage in district heating / cooling.
11. Flexibility in electricity network by heat pump to avoid peak power.
12. Excess heat recovery to district heating and cooling.
13. Prosumer.

More detailed descriptions of the business concepts developed include the key stakeholders, their interactions and information needs for evaluating the specific business cases. Cost and benefit evaluations and proving of economic viability of the built business models are case-specific and depend on the details of each model. Two examples of the business concepts developed are presented in Appendix D: Paper IV: Sepponen and Heimonen [2015]: 1) an energy broker, and 2) an integrated multi-actor concept. One example of applying the business concept elements to build business models is given in Appendix D [Paper IV] here the elements were used to propose possible district energy services for a district case located in Dalian, China.

Energy trading and brokering theme was brought up also by Sepponen and Tommis [2013], which introduced a (district) energy broker as one of the future scenarios for smart and energy efficient future neighbourhoods. This energy broker would sell and buy energy on behalf of their customers (energy consumers, prosumers, and distributed energy producers). Here, the broker had many means for energy balancing, including demand side management (as agreed with customers), control of non-fluctuating energy production sources (from renewable energy sources), and local energy storage (including electric vehicles). This future scenario suggested that energy trading could be further developed to support the new energy systems, increasing the share of fluctuating renewable energy sources, and the balancing between energy supply and demand at the district level. Energy trading inside the district would support local energy balancing, and reduce the needed maximum electricity distribution capacities between the built area and national electricity grid. Also, the ownership of energy distribution networks in such arrangements should to be rethought, as well as the pricing of energy distribution and its taxes.

6.4 Barriers and challenges of new business concepts

Only some of the suggested business concepts are easily feasible today, including the following concepts: 1, 2, 6, 8, 9, 10, 11, and 12. Other proposed concepts have some actors and roles that do not widely exist yet. Even if it were possible to demonstrate, for example, an energy brokering tool in a use case, there is still a need for a district energy services operator, which does not exist today [Sepponen and Heimonen, 2016]. There is a need for demonstration cases that can give measured data of the success of the business models.

The realisation of the new business concepts requires profound evaluation of risks and success factors, as noted in Paper IV: Sepponen and Heimonen, 2016. In general, it is also valuable to acknowledge the barriers to new business concepts, which were also evaluated in Paper IV: Sepponen and Heimonen, 2016. However, Szatow et al. [2012] have, for instance, argued that new energy services business will overcome many traditional barriers, e.g. the need for a carbon emission price or separating the profitability of an energy company from the growth of energy demand.

As noted in Paper IV, a legal framework can set barriers to the real life implementation of suggested business concepts. For example, legal issues could hinder the competition of contracts and offered energy services. In addition, some models require information that is not yet publicly available. Some challenges could also rise from the data privacy conservation related to individual consumers' real time energy consumption data. However, also solutions and guidelines for overcoming open data publication and use-related challenges have recently been addressed e.g. by Radulovic et al. [2015]. Additional ways to overcome these issues are e.g. for an energy company to contractually agree with its customers to access and utilise the individual energy consumption data [Paper IV].

6.5 Why the same model does not work in all similar districts?

A wide variety of sustainable energy solutions and technologies exists already, but for the wide-scale roll-out they need to be repackaged in a new way, resulting in improved energy efficiency and reduced primary energy demand and related emissions [Szatow et al., 2012]. This kind of development of energy service business can align the interests among many stakeholders, including municipalities, end users, and energy service providers.

New energy services can be created through different paths, but in many cases the building sector, e.g. housing organisations and facility managers, can have a significant role in identifying new alternatives for organizing and offering the energy services based on repackaging product and service combinations according to consumers' needs (as so-called result- or need-oriented service model). This is also one of the reasons, why it is important to localise the business models, and why, in the end, a cookbook of business model elements was created instead of fixed business models.

Typically, real business models need to be unique and localised. The cookbook and its business concept elements are building blocks, which value comes from combining these into specific business models and cases. The potential stakeholders benefitting from this work are mapped in Table 14, including energy companies and energy service providers, but also active end-uses, such as large facility managers, who could find new business opportunities related to energy balancing and utilising of flexibility.

7. Conclusions and recommendations

Achieving energy efficient and sustainable district requires holistic energy planning, smart energy management and optimal utilisation of various energy sources. These are increasingly important in the near future, when many policy frameworks are leading to tightening energy efficiency and emission regulations and increasing the share of locally produced renewable energy. These policies will cause changes to the planning and management of energy systems, especially at the local level. This will also lead to new emerging business opportunities related to the local energy systems. The main elements of the foreseen changes in the district energy systems are visualised in Figure 52.

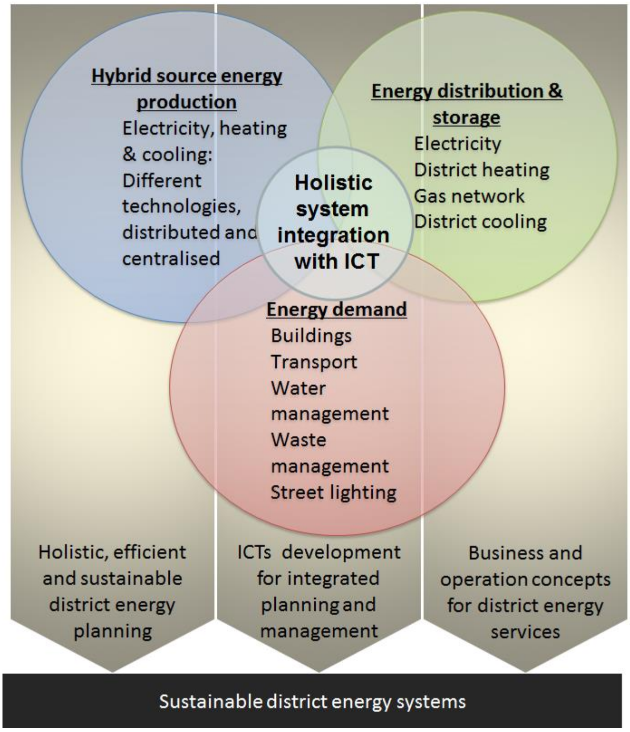


Figure 52. Main elements of energy efficient sustainable district energy systems.

This dissertation studied the energy efficient and sustainable district energy systems. The main focal research areas were: 1) district energy analyses supporting urban planning, and 2) business opportunities for district energy services and systems. As a result of this research are the following complementary conclusions:

- District energy planning should be included early in the urban planning process. Planners and decision-makers must have an understanding of the effects resulting from design choices and their relation to the energy system and its emissions. District energy planning should optimise the entire energy chain, taking into account optimal use of hybrid energy sources, the efficient energy utilisation in the built environment and smart energy balancing.

- New potential business opportunities are foreseen in the management of energy systems, as well as in energy distribution, balancing and trading at the district level. District energy business can be arranged in many different ways depending on the participating actors and local operation environment. Hence, instead of fixed business models, a set of business concept elements were developed in a form of a cook book. These elements can be combined and modified to develop localised business cases and models.

7.1 District energy analyses as a part of sustainable urban planning

City planners and municipal authorities make many design choices that impact districts' energy efficiency and emissions significantly during urban planning. In practical terms, they often have challenges related to the lack information about the actual effects of their design and decision options. They need fast and practical analysis methods, which would offer feedback on impacts of different urban planning options.

The first main research aim of this dissertation was to support energy efficient and sustainable urban planning by analysing the energy performance of districts and comparing the environmental impacts of urban planning decisions to the energy system alternatives. Here the emphasis was on how each district could be planned as efficiently and sustainable as possible. This was due to the fact that the land use and urban plans are primarily defined according to the high level municipal needs and goals related to social aspects, needs for services, spaces and buildings, transportation system boundaries and targets, etc.

The district energy analysis needs to take a holistic view of the local energy system, including different energy demands of buildings and transport. As concluded in Paper II [Paiho et al., 2014], better improvements are often achieved when considering the whole energy chain of districts. In general, the district energy analyses showed that heat demand savings can be achieved typically more easily than electricity savings, because electricity demand is more strongly related to people behaviour.

The district energy analysis methodology was developed iteratively during 14 real life case studies. Then, based on these findings and lessons, a district energy and emission analysis tool was developed [Paper V] for evaluating and comparing the impacts of urban planning choices on the annual energy demand and the embedded CO_2 equivalent emissions of urban areas, as recommended e.g. by Marigue and Reiter [2014]. The developed tool and its base data are applicable in Finland, but the methodology itself can be localised to other countries, if a suitable base data is available, which was shown by including 4 case analysis from Russia in this dissertation.

As urban planners and other experts required, the district energy analysis methodology and the tool were kept as straight-forward as possible, with the aim to shorten the needed analysis time and improve the user friendliness. This required balancing between the appropriate level of the analysis detail in relation to the practicality and the time needed for making the analysis.

The district energy analysis could give the highest value, if it would be utilised in the early urban planning phase. Then, the analysis results could aid planners and decision makers to see the impacts of planning choices simultaneously when developing the plans. The results of the district energy analysis can also foster discussion and evaluation of alternative energy system planning choices to traditional design. The developed tool has been already used in a few Finnish municipalities with a good feedback from test users.

7.2 Business concepts for district energy systems and services

There exists already a wide variety of technologies enabling sustainable and smart energy supply in districts with a high share of local, distributed and renewable energy supply. As a consequence, one of the today's main challenges is to find the best possible business models for arranging district energy service business and system operation.

Paper IV [Sepponen and Heimonen, 2016] proposed a set of potential district energy service and business concepts in a form of a cookbook. These concepts were kept simple and focusing only to one seller-buyer service or product concept at a time. The value of these business model elements comes from combining them to practical business models and cases. At best, these business models are localised according to the local conditions.

Many of the suggested business concepts considered expected future trends and stakeholders' requirements for emerging smart energy services. In total 5 business concepts were built around the energy balancing trend, where energy consumers and producers could take business advantage from utilising their flexibility in energy production and consumption.

7.3 Smart district energy systems

There is a wide variety of opportunities to improve overall energy efficiency and sustainability of urban areas and their energy systems by holistic design and optimal energy management of different energy systems. However, the near future changes in the energy systems can make the designing and the management of the district energy systems more complex. The number of stakeholders involved in the management of energy systems grows, when the energy is supplied increasingly from hybrid energy sources and buildings and other energy consumers are becoming more active nodes in the energy system. These challenges can be (at least partially) supported and solved by various ICT and smart city developments.

Smart systems are needed in maximising the overall efficiency of utilising various energy sources in optimal way among a wide operation network with many energy suppliers, distribution networks and energy utilisers. Here, ICT solutions play a key role, and their future requirements have been suggested e.g in following research: Sepponen and Tommis [2013], Sepponen et al., 2013 and Hukkalainen et al., 2015. These publications have studied increasing the use of fluctuating renewable energy sources, which increase the importance of optimising both the utilisation of energy sources and the energy use. As a consequence, the optimal energy system management and balancing of the energy demand and supply is important. Energy balancing methods include among others peak shifting and shaving, energy storage use, and adjusting of energy supply. The most important supporting ICT systems could include different energy system management and energy trading applications for building, district and city levels [Sepponen and Tommis, 2013].

The large number of stakeholders increases the need for integrating the energy system and related processes. As a consequence, synergy benefits could be achieved e.g. from finding new energy sources and load balancing opportunities. Potential energy and city systems, which could bring additional energy savings and benefits are mapped in Figure 53. Integration solutions could ease also the collaboration among the planners, municipality, energy and building companies, as well as to support involving of end users.

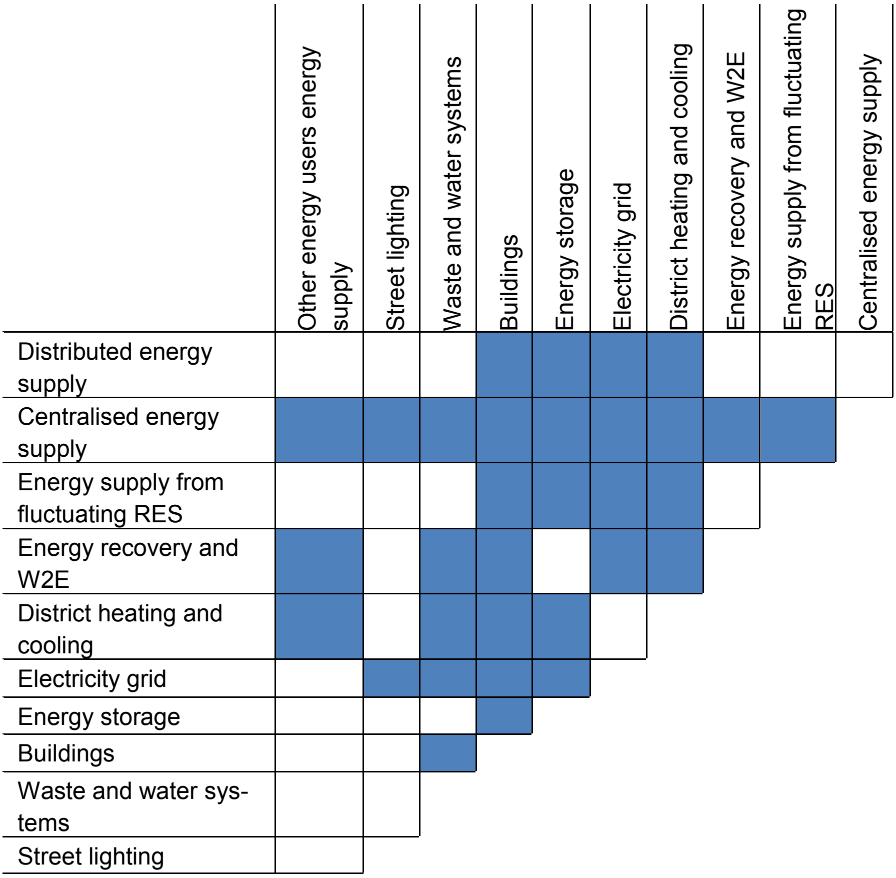


Figure 53. A mapping of cities' energy systems, where potential integration points between different energy systems have been marked with blue [Hukkalainen et al., 2015].

7.4 Recommendations for stakeholders

A wide variety of stakeholders need to be involved and collaborating, when aiming at sustainable, efficient and low emission districts and their energy systems. They can be divided to four main categories: municipality, energy sector, building sector, and citizens, as was done in Ready4SmartCities roadmap in Hukkalainen et al. [2015]. The roles and recommendations for each stakeholder group are summarised here.

Municipalities and urban planners have the central role in effecting environmental sustainability locally through decisions related to urban and transport planning, used energy sources and city infrastructures. Often, municipality needs to act as an enabler and starter for developing and improving sustainability of districts. It can set targets and goals for the urban area development and bring together different stakeholders needed in the planning and implementation of actions. The role of urban planning is to create such an urban plan that enables a flexible base and sets the boundaries for designing and implementing different sustainable energy system choices. It doesn't necessarily need to set fixed energy system and performance levels, but it can guide and encourage to energy efficient built environment. Most importantly, a good urban plan enables, or at least do not restrict, planning of energy efficient buildings and city infrastructure. In practise, this means e.g. that plots and the placing and orientation of buildings could be set with taking into account the maximum solar energy production potential. The role of urban planning in district energy systems needs also performance estimation and benchmarking of sustainable development.

Energy utilities and companies are collaborating with the municipality when starting to plan the energy systems of districts. In this, they can also benefit from early stage district energy analysis results. Likely, energy companies can get the highest benefits with developing and deploying solutions for planning and managing the local energy systems as efficiently as possible. Especially they could support holistic coordination and optimisation of the use of hybrid energy sources and their balancing with the energy demand. New business opportunities are foreseen to emerge for local energy systems and related energy services and energy trading. These business opportunities could be adopted either by existing or new energy sector operators and companies.

Building sector operators, such as construction companies and facility managers, need to develop and adopt new energy efficient building solutions when the building regulations are tightening and we are approaching nearly zero energy building targets. In the near future, buildings need to be increasingly planned and managed as an active part of the energy system. The building planners and construction companies will benefit from tools and systems for optimal design of building energy performance. Development of integrated design and collaboration tools will also support efficient building design and construction. On the other hand, facility managers bear the responsibility of managing the building and its energy system as efficiently as possible. Energy balancing and load control can bring additional challenges, but also new economic savings through optimal building performance management.

End-users' role is emphasised more and more nowadays also in the energy systems. ICT can offer means for involving end-users more efficiently, and giving them easy opportunities to influence and give feedback e.g. about urban plans. Supporting, guiding and benchmarking applications are, and will be, developed for end-uses and citizens to improve the energy performance or minimising their energy costs and/or their carbon footprint in their everyday activities

7.5 Towards low carbon district energy systems

It is concluded that achieving truly low carbon, efficient and sustainable districts and their energy systems required wide collaboration and holistic coordination of different city systems, buildings, infrastructure, and transport, etc. The key highlights and conclusions from this dissertation for achieving low carbon districts are summarised in Figure 54, which presents the current situation, the required changes and developments to realise the vision for low carbon districts and their energy systems.

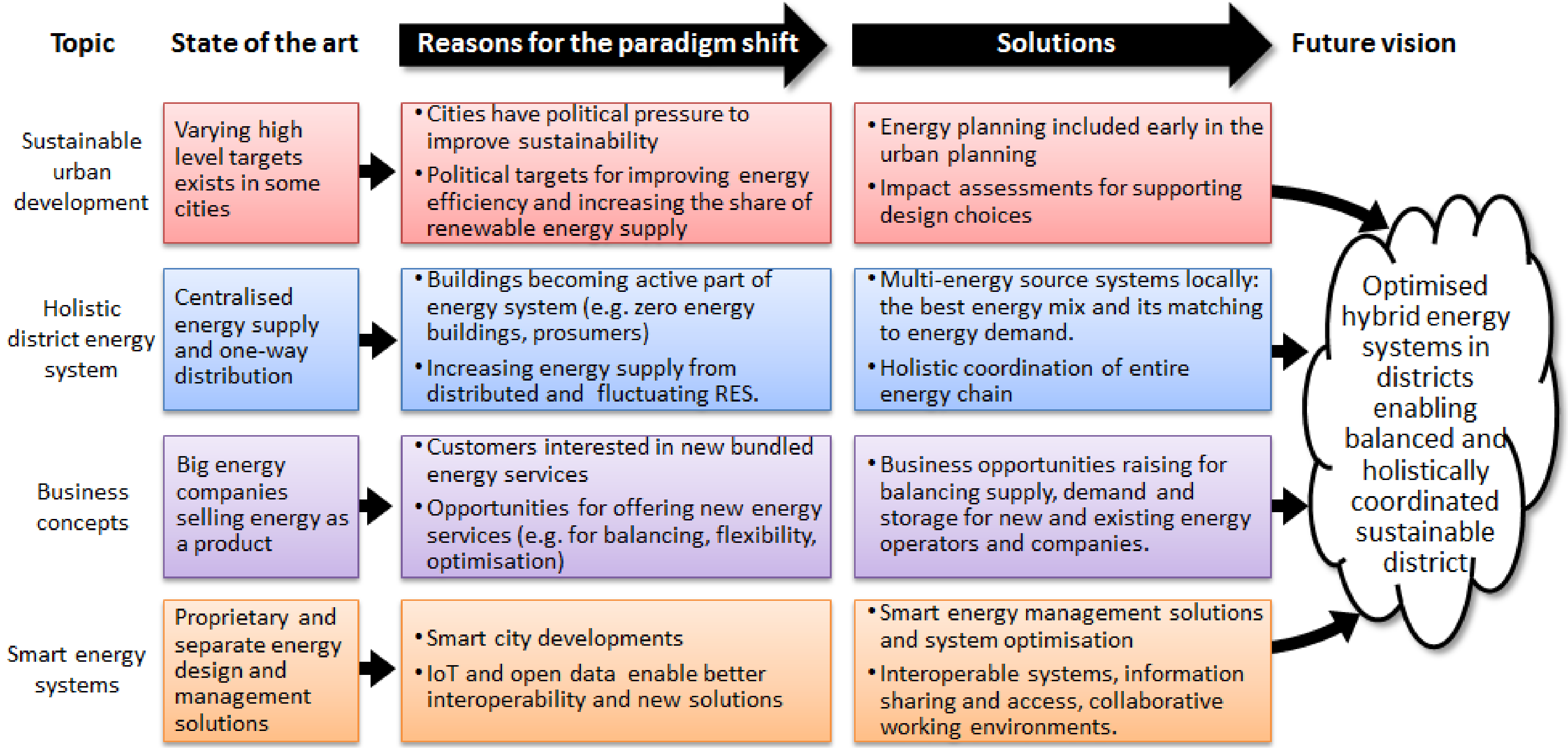


Figure 54. A summary of requirements for improving the sustainability of districts and their energy systems with integrated and holistically coordinated energy supply, distribution and demand.

References

Adhikari R.S., Aste N., Manfren M., 2011: Optimization concepts in district energy design and management – A case study. Energy Procedia, Volume 14, 2012, Pages 1386–1391, ISSN 1876-6102, http://dx.doi.org/10.1016/j.egypro.2011.12.1106

Airaksinen M. (ed.), 2011: Research highlights in energy and eco-efficient built environment. VTT Research Highlights 1. VTT, Espoo, Finland. 200 p. ISBN 978-951-38-7820-7. Available [accessed 27.01.2016]: http://www.vtt.fi/inf/pdf/researchhighlights/2012/R1.pdf

Ala-Juusela M., Sepponen M., Crosbie T., 2014: Defining the concept of an Energy Positive Neighbourhood and related KPIs. Sustainable Places in Nice, France, in October 1–3, 2014. Conference paper and presentation. Short proceedings available, pp. 66–67: [accessed 13.11.2015] http://sustainable-places.eu/wp-content/uploads/2014/10/SP14_Proceedings_281014.pdf

Alavy M., Dworkin S.B., Leong W.H., 2014: A design methodology and analysis of combining multiple buildings onto a single district hybrid ground source heat pump system. Renewable Energy, Volume 66, June 2014, Pages 515–522, ISSN 0960-1481, http://dx.doi.org/10.1016/j.renene.2013.12.030

Albino V., Berardi U., Dangelico R.M., 2015: Smart Cities: Definitions, Dimensions, Performance, and Initiatives. Journal of Urban Technology, Volume 22, Issue 1, 2015, Pages 3–21. DOI: 10.1080/10630732.2014.942092

Azevedo I., Delarue E., Meeus L., 2013: Mobilizing cities towards a low-carbon future: Tambourines, carrots and sticks. Energy Policy, Volume 61 (2003), Pages 894–900.

Baker E., Bosetti V., Diaz Anadon L., Henrion M., Reis L.A., 2015: Future costs of key low-carbon energy technologies: Harmonization and aggregation of energy technology expert elicitation data. Energy Policy, Volume 80, May 2015, Pages 219–232, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2014.10.008

Bazmi A.A., Zahedi G., 2011: Sustainable energy systems: Role of optimization modeling techniques in power generation and supply – A review. Renewable and Sustainable Energy Reviews, Volume 15, Issue 8, October 2011, Pages 3480–3500, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2011.05.003

Bhatt V., Friley P., Lee J., 2010: Integrated energy and environmental systems analysis methodology for achieving low carbon cities. Journal of Renewable and Sustainable Energy, Volume 2, 031012 (2010). http://dx.doi.org/10.1063/1.3456367

Bleyl-Androschin J.W., Ungerböck R., 2009: What is Energy Contracting (ESCo services)? Concept, Definition, Two Basic Business Models. Discussion paper. IEA DSM TASK XVI "Competitive Energy Services". Grazer Energieagentur GmbH. Available at: http://www.grazer-ea.at/eesi/upload/download/diskussionspapiere/091018_gea_energy_contracting_definitions-discussion_paper.pdf [accessed 19.11.2015]

Boait P., 2009: Energy Services and ESCOs – their benefits and implications for regulation and the consumer. Institute of Energy and Sustainable Development, De Montfort University. Report part of PRI-X@20 project

Brandoni C., Polonara F., 2012: The role of municipal energy planning in the regional energy-planning process. Energy, Volume 48, Issue 1, December 2012, Pages 323–338. doi:10.1016/j.energy.2012.06.061

BREAAM Communities, 2012: Technical Manual SD202 – 1.0:2012. BRE Global Ltd: 2014. Available [accessed 23.3.2015] http://www.breeam.org/communitiesmanual/

Cardenas J.A., Gemoets L., Ablanedo Rosas J.H., Sarfi R., 2014: A literature survey on Smart Grid distribution: an analytical approach. Journal of Cleaner Production, Volume 65, 15 February 2014, Pages 202–216, ISSN 0959-6526, http://dx.doi.org/10.1016/j.jclepro.2013.09.019

Carosia S., Hannus M., Mastrodonato C., Delponte E., Cavallaro A., Cricchio F., Karnouskos S., Pereira-Carlos J., Bastos Rodriguez C., Nilsson O., Pinto Seppä I., Sasin T., Żach J., van Beurden H., Anderson T., 2013: ICT Roadmap for Energy-Efficient Buildings Research and Actions. 129 p. Available [accessed 27.01.2016]: http://ict4e2b.atosresearch.eu/sites/ict4e2b.atosresearch.eu/files/page-files/13/ICT4E2B%20Forum%20Book.pdf

Carpaneto E., Lazzeroni P., Repetto M., 2015: Optimal integration of solar energy in a district heating network. Renewable Energy, Volume 75, March 2015, Pages 714–721, ISSN 0960-1481, http://dx.doi.org/10.1016/j.renene.2014.10.055

CASBEE for Urban Development, Technical manual, 2014 Edition. Institute for Building Environment and Energy Conservation (IBEC).

Charoenkit S., Kumar S., 2014: Environmental sustainability assessment tools for low carbon and climate resilient low income housing settlements. Renewable and Sustainable Energy Reviews, Volume 38, October 2014, Pages 509–525. doi:10.1016/j.rser.2014.06.012

City of Jämsä, 2010: District plan of Könkkölä area in Jämsä. Figure got from urban planners of Jämsä in summer 2010.

City of Tampere, 2011: Land use plan for the Koukkuranta in Vuores. Urban plan description. City of Tampere. Available [accessed 10.1.2016]: http://www.tampere.fi/cgi-bin/kaava/kaavadoc?8263

City of Toivakka, 2010: District plan for Saarinen area. Figure got from urban planners of Toivakka in 18.8.2010.

Covenant of Mayors, 2015: Covenant of Mayors – committed to local sustainable energy. Available [accessed 22.10.2015]: http://www.covenantofmayors.eu/about/covenant-of-mayors_en.html

Di Giorgio A., Liberati F., 2014: Near real time load shifting control for residential electricity prosumers under designed and market indexed pricing models. Applied Energy, Volume 128, 1 September 2014, Pages 119–132, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2014.04.032

EC, 2010/31: Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. Available: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32010L0031 [accessed 22.9.2014]

EC, 2012: Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. Document 32012R0244. Available: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32012R0244 [accessed 17.9.2014]

EC, 2014a: 2030 framework for climate and energy policies. Climate action. Web page. Available [accessed 17.9.2014]: http://ec.europa.eu/clima/policies/2030/index_en.htm

EC, 2014b: The climate and energy package. Climate action. Webpage of European Commission. Available [accessed 17.9.2014]: http://ec.europa.eu/clima/policies/package/index_en.htm

EC DG JRC, 2010: European Commission Joint Research Centre Institute for Energy, 2010, ‘Energy Service Companies Market in Europe, Status Report 2010’. Available [accessed 19.11.2015]: http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/15108/1/jrc59863%20real%20final%20esco%20report%202010.pdf

Eicker U., Monien D., Duminil É., Nouvel R., 2015: Energy performance assessment in urban planning competitions. Applied Energy, Volume 155, 1 October 2015, Pages 323–333, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2015.05.094

EPA, 2012: Particulate Matter (PM), United States United States Environmental Protection Agency (EPA). http://www.epa.gov/airquality/particlepollution/ [accessed 1.10.14].

European Parliament and Council, 2008: Commission Decision C(2008)30 final. 20 20 by 2020 Europe’s climate change opportunity. Commission of The European Communities, 2008.

Fang T., Lahdelma R., 2014: State estimation of district heating network based on customer measurements. Applied Thermal Engineering, Volume 73, Issue 1, 5 December 2014, Pages 1209–1219, ISSN 1359-4311, http://dx.doi.org/10.1016/j.applthermaleng.2014.09.003

Finnish Energy Industries, 2014a: Energy year 2013 – Electricity. Finnish Energy Industries 21.1.2014. ppt-presentation. Available [accessed 29.9.2014]: http://energia.fi/sites/default/files/energy_year_2013_0.ppt

Finnish Energy Industries, 2014b: Energy year 2013 – District heating. Finnish Energy Industries 21.1.2014. ppt-presentation. Available [accessed 29.9.2014]: http://energia.fi/sites/default/files/districtheating_2013.pptx

Finnish Wind Atlas web tool, 2009: Developed by Finnish Meteorological Institute of Finland in 2009. Available [accessed 7.8.2015] at: http://tuuliatlas.fmi.fi/en/

Finnveden G., Hauschild M.Z., Ekvall T., Guinée J., Heijungs R., Hellweg S., Koehler A., Pennington D., Suh S., 2009: Recent developments in Life Cycle Assessment. Journal of Environmental Management, Volume 91, Issue 1, October 2009, Pages 1–21, ISSN 0301-4797, http://dx.doi.org/10.1016/j.jenvman.2009.06.018

Flynn C., Sirén K., 2015: Influence of location and design on the performance of a solar district heating system equipped with borehole seasonal storage. Renewable Energy, Volume 81, September 2015, Pages 377–388, ISSN 0960-1481, http://dx.doi.org/10.1016/j.renene.2015.03.036

Fritsche U.R., Schmidt K.I., 2008: Global Emission Model of Integrated Systems (GEMIS 4.5) Manual, Ökö-Institut (Institute for Applied Energy), 2008.

GEMIS database, 2010: The database of the GEMIS tool (Global Emissions Model for integrated Systems). Software available from: http://www.iinas.org/gemis.html

Good N., Martínez Ceseña E.A., Zhang L., Mancarella P., 2015: Techno-economic and business case assessment of low carbon technologies in distributed multi-energy systems. Applied Energy, Available online 18 October 2015, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2015.09.089

Government of Finland, 2008: Long-term Climate and Energy Strategy. Government Report to Parliament 6 November 2008. Available: http://www.tem.fi/files/20587/Climate_Change_and_Energy_Strategy_2008_summary.pdf [Accessed 22.10.2015].

Government of Finland, 2009: Government Foresight Report on Long-term Climate and Energy Policy: Towards a Low-carbon Finland. Prime Minister's Office Publications 30/2009. ISBN PDF 978-952-5807-70-7, ISBN print 978-952-5807-69-1 Available [accessed 22.10.2015]: http://vnk.fi/documents/10616/622958/J3009+Government+Foresight+Report+on+Long-term+Climate+and+Energy+Policy.pdf/bd1eabff-7ce1-424d-8fce-e150dd1a0653

Government of Finland, 2013: National Energy and Climate Strategy. Government Report to Parliament on 20 March 2013. Available: http://www.tem.fi/files/36292/Energia-_ja_ilmastostrategia_nettijulkaisu_ENGLANNINKIELINEN.pdf [Accessed 8.10.2015]

Gröger G., Plümer L., 2012: CityGML – Interoperable semantic 3D city models. ISPRS Journal of Photogrammetry and Remote Sensing, Volume 71, July 2012, Pages 12–33, ISSN 0924-2716, http://dx.doi.org/10.1016/j.isprsjprs.2012.04.004

Gustavsson L., Dodoo A., Truong N.L., Danielski I., 2011: Primary energy implications of end-use energy efficiency measures in district heated buildings. Energy and Buildings, Volume 43, Issue 1, January 2011, Pages 38–48, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2010.07.029

Haapio A., 2012: Towards sustainable urban communities. Environmental Impact Assessment Review Volume 32, Issue 1, January 2012, Pages 165–169. doi:10.1016/j.eiar.2011.08.002

Hagström M., Vanhanen J., Vehviläinen I., 2009: Kevennetty kaukolämpötekniikka – Kustannustehokkaan jakelu- ja asiakasteknologian kehittäminen matalan kulutustason olosuhteisiin. In Finnish (Lighter district heating.) Final report 30.9.2009. Gaia Consulting. Available [accessed 1.12.2015]: http://energia.fi/julkaisut/kevennetty-kaukolampotekniikka-kustannustehokkaan-jakelu-ja-asiakasteknologian-kehittamine

Hakaste H., Jalkanen R., Korpivaara A., Rinne H., Siiskonen M., 2005: Eco Viikki – Aims, implementation and results. Report. City of Helsinki and Ministry of Environment, Finland. ISBN 952-473-455-9. Available [accessed 27.01.2016]: www.hel.fi/hel2/taske/julkaisut/2009/eco-viikki_en_net.pdf

Hannus M., Kazi A.S. (Sami), Zarli A. (ed.), 2010: ICT Supported Energy Efficiency in Construction – Strategic Research Roadmap and Implementation Recommendations. REEB. 162 p. Available online [accessed 20.10.2015]: http://ec.europa.eu/information_society/activities/sustainable_growth/docs/sb_publications/reeb_ee_construction.pdf

Hannus M., Delponte E., 2012: Roadmap on ICT 4 E2B. Presentation summarising the roadmap. Project: ICT 4 E2B Forum – European stakeholders' forum crossing value and innovation chains to explore needs, challenges and opportunities in further research and integration of ICT systems for Energy Efficiency in Buildings. E2BA roadmap workshops, Paris, 24–26th April 2012. Available [accessed 20.11.2015]: http://ict4e2b.atosresearch.eu/sites/ict4e2b.atosresearch.eu/files/event-files/e2ba_roadmap_2012042426mh-eld-cut.pdf

Hannus M., Ellis K., Fies B., Fouchal F., Hassan T., Kuhn D., Lappalainen V., Lindow K., Pille H., Tetri E., Vlug N., 2012: D3.2 Multi-disciplinary Strategic Research Agenda for ICT-enabled Energy Efficiency. ReViSITE project deliverable (Roadmap Enabling Vision and Strategy for ICT-enabled Energy Efficiency). Available [accessed 20.11.2015]: http://www.revisite.eu/docs/REViSITE_deliverable_D3.2_main_report.pdf

Hassan A.M., Lee H., 2015: Toward the sustainable development of urban areas: An overview of global trends in trials and policies. Land Use Policy, Volume 48, November 2015, Pages 199–212, ISSN 0264-8377, http://dx.doi.org/10.1016/j.landusepol.2015.04.029

Heimonen I., Himanen M., Junnonen J.-M., Kurnitski J., Mikkola M., Ryynänen T., Vuolle M., 2007: Tools for life cycle models in building service technology. CLIMA 2007 Well being Indoors, 9th REHVA World Congress, 10–14 June 2007, Helsinki. Proceedings, Vol. 3. FINVAC ry, pages 445–452.

Heimonen I., Sepponen M., Virtanen M., Jung N., Ahvenniemi H., Kohonen R., Kessels K., Oostra M., Huygen A., Koene F., Laialo P., Piai C., Urbano

G., Jablonska B., Szymanska K., Alberti M., Mutti A., Baragiola F., 2012: D6.1 Description of market needs and business models in area of district level energy services. Research project deliverable from project E-HUB: Energy-Hub for residential and commercial districts and transport. EC 7th framework programme project. Available [accessed 19.11.2015]: http://www.e-hub.org/pdf/D6.1_Market_needs_and_business_models_in_district_energy.pdf

Heinonen J., 2012: The Impacts of Urban Structure and the Related Consumption Patterns on the Carbon Emissions of an Average Consumer. Doctoral dissertation for the degree of Doctor of Science in Technology, School of Engineering, Aalto University School of Science, Espoo, Finland). Available [accessed 12.11.2015]: http://lib.tkk.fi/Diss/2012/isbn9789526045368/isbn9789526045368.pdf

Helsinki, 2013: Strategy Programme 2013–2016, City of Helsinki. Helsinki City Council 24 April 2013. Available [accessed 21.10.2014]: http://www.hel.fi/static/taske/julkaisut/2013/Strategy_Programme_2013-2016.pdf

Helsinki region infoshare, 2014: Open data from the Helsinki Metropolitan Area for you to use freely. City of Helsinki Urban Facts. Website (accessed 25.9.2014): http://www.hri.fi/en/

Hinku, 2015: Towards carbon neutral municipalities – HINKU Forum. Webpage, accessed 22.10.2015: http://www.hinku-foorumi.fi/en-US

Hiremath R.B., Shikha S., Ravindranath N.H., 2007: Decentralized energy planning; modeling and application – a review. Renewable and Sustainable Energy Reviews, Volume 11, Issue 5, June 2007, Pages 729–752, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2005.07.005

Huang Z., Yu H., Peng Z., Zhao M., 2015: Methods and tools for community energy planning: A review. Renewable and Sustainable Energy Reviews, Volume 42, February 2015, Pages 1335–1348, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2014.11.042

Hukkalainen M., Hannus M., Piira K., Grahn E., Hoang H., Andrea C., García-Castro R., Fies B., Tryferidis T., Tsagkari K.-Z., Euzenat J., Judex F., Basciotti D., Marguerite C., Schmidt R.-R., Strahil B., Robinson S., Vogt G., 2015: Deliverable D5.6 Innovation and research roadmap. Ready4SmartCities project, available [accessed 7.12.2015]: http://www.ready4smartcities.eu/documents/38385/120604/D5.6+Innovation+and+Research+Roadmap/b1b0d043-1abd-49de-b69c-92e93c1adb91

Hyyti K., 2011: Draft of the land use plan of Kaistinmäki district in municipality of Petäjävesi. A-konsultit.

IDA ICE, 2014: DA Indoor Climate and Energy. Webpage by EQUA Simulation AB. Available [accessed 30.9.2014]: http://www.equa.se/index.php/en/ida-ice

IEA, 2014: Technology Roadmap – Solar Photovoltaic Energy. 2014 Edition. Internal Energy Agency. Available [accessed 30.9.2014]: http://www.iea.org/publications/freepublications/publication/Technology-RoadmapSolarPhotovoltaicEnergy_2014edition.pdf

IINAS, 2014: Global Emission Model for Integrated Systems: GEMIS database and software. The International Institute for Sustainability Analysis and Strategy (IINAS), Germany. Information and freely available tool: http://www.iinas.org/gemis-en.html

IPCC, 2014: Climate Change 2014: Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available [accessed 21.10.2015]: http://mitigation2014.org/report/publication/

ISO, 2006: ISO 14040 International standard. In: Environmental Management – Life Cycle Assessment – Principles and Framework. International Organisation for Standardisation, Geneva, Switzerland.

Johansson P., Nylander A., Johnsson F., 2007: Primary energy use for heating in the Swedish building sector – Current trends and proposed target. Energy Policy, Volume 35, Issue 2, February 2007, Pages 1386–1404, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2006.03.025.

Jyväskylä municipality, 2010: draft urban plan of the Säynätsalon kouluranta area in the city of Jyväskylä. Figure and information from urban planners working in the city planning department in the municipality of Jyväskylä.

Järvenpään mestariasunnot, 2011: Suomen ensimmäinen nollaenergiatalo nousi Järvenpäähän (The first Finnish zero energy building built in Järvenpää). In Finnish. News item by the construction company. Available in Finnish: http://www.mestariasunnot.fi/nollaenergiahanke.php [accessed 22.10.14]

Kılkış Ş., 2014: Energy system analysis of a pilot net-zero exergy district. Energy Conversion and Management, Volume 87, November 2014, Pages

1077–1092, ISSN 0196-8904, http://dx.doi.org/10.1016/j.enconman.2014.05.014

Klessmann C., Held A., Rathmann M., Ragwitz M., 2011: Status and perspectives of renewable energy policy and deployment in the European Union – What is needed to reach the 2020 targets? Energy Policy 39(2011) 7637–7657.

Klobut K., Heikkinen J., Shemeikka J., Laitinen A., Rämä M., Sipilä K. 2009: Huippuenergiatehokkaan asuintalon kaukolämpöratkaisut. VTT Tiedotteita – Research Notes 2513. Espoo, VTT. 68 p.
ISBN 978-951-38-7541-1. Available: http://www.vtt.fi/inf/pdf/tiedotteet/2009/T2513.pdf

Koskelainen L., Saarela R., Sipilä K., 2006: Kaukolämmön käsikirja. In Finnish (District heating handbook). Published by The Finnish Energy (ET). ISBN 952-5615-08-1. Helsinki, Finland.

Kosonen R., Shemeikka J., 1997: The use of simple simulation tool for energy analysis. Building Simulation '97. 5th International IBPSA Conference. Prague, 8–10 Sept. 1997, pp. 369–376. Available [accessed 30.9.2014]: www.ibpsa.org/%5Cproceedings%5CBS1997%5CBS97_P103.pdf

Kramers A., Wangel J., Johansson S., Höjer M., Finnveden G., Brandt N., 2013: Towards a comprehensive system of methodological considerations for cities' climate targets. Energy Policy, Volume 62, November 2013, Pages 1276–1287, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2013.06.093.

Kramers A., Höjer M., Lövehagen N., Wangel J., 2014: Smart sustainable cities – Exploring ICT solutions for reduced energy use in cities. Environmental Modelling & Software, Volume 56, June 2014, Pages 52–62, ISSN 1364-8152, http://dx.doi.org/10.1016/j.envsoft.2013.12.019

Kumar P., Geneletti D., 2015: How are climate change concerns addressed by spatial plans? An evaluation framework, and an application to Indian cities. Land Use Policy, Volume 42, January 2015, Pages 210–226, ISSN 0264-8377, http://dx.doi.org/10.1016/j.landusepol.2014.07.016

Kylili A., Fokaides P.A., 2015: European smart cities: The role of zero energy buildings. Sustainable Cities and Society, Volume 15, July 2015, Pages 86–95, ISSN 2210-6707, http://dx.doi.org/10.1016/j.scs.2014.12.003

Lahti P., Nieminen J., Virtanen M., 2008: Ekotehokkuuden arviointi ja lisääminen Helsingissä. In Finnish. Eco efficiency evaluation and improvements in

Helsinki. VTT Reseach report VTT-R-05674-08. Available (accessed 11.11.2015): http://www.hel2.fi/ksv/julkaisut/yos_2008-2.pdf

Lahti P., Nieminen J., Nikkanen A., Puurunen E., 2010: Helsingin kaavoituksen ekotehokkuustyökalu (HEKO) (in Finnish, Eco efficiency tool for city planning in the city of Helsinki). VTT, Espoo. Available [accessed 11.11.2015]: http://www.hel.fi/static/public/hela/Kaupunkisuunnittelulautakunta/Suomi/Esitys/2010/Ksv_2010-11-11_Kslk_32_El/547EC356-9F25-4E0E-87E6-FD71878F5B6F/HEKO2-raportti_04112010_valmis.pdf

Lahti P., Sepponen M., Virtanen M., 2012: Kunnallisten rakennushankkeiden kestävät energiaratkaisut aluenäkökulmasta. In Finnish (Sustainable energy solutions for municipal construction projects from the district perspective). Research report VTT-R-07915-12.
VTT, Espoo. 59 p. Available [accessed 16.12.2015]:
http://www.vtt.fi/inf/julkaisut/muut/2012/VTT-R-07915-12.pdf

LEED for Neighbourhood Development, 2009: The U.S. Green Building Council. Updated July 20144. Available [accessed 23.3.2015]:
http://www.usgbc.org/sites/default/files/LEED%202009%20RS_ND_07.01.14_current%20version.pdf

Loiseau L., Junqua G., Roux P., Bellon-Maurel V., 2012: Environmental assessment of a territory: An overview of existing tools and methods. Journal of Environmental Management, Volume 112, 15 December 2012, Pages 213–225. doi:10.1016/j.jenvman.2012.07.024

Lotteau M., Loubet P., Pousse M., Dufrasnes E., Sonnemann G., 2015: Critical review of life cycle assessment (LCA) for the built environment at the neighborhood scale. Building and Environment, Volume 93, Part 2, November 2015, Pages 165–178, ISSN 0360-1323,
http://dx.doi.org/10.1016/j.buildenv.2015.06.029

Lu Y., Wang S., Shan K., 2015: Design optimization and optimal control of grid-connected and standalone nearly/net zero energy buildings. Applied Energy, Volume 155, 1 October 2015, Pages 463–477, ISSN 0306-2619,
http://dx.doi.org/10.1016/j.apenergy.2015.06.007

Lundström L., Wallin F., 2016: Heat demand profiles of energy conservation measures in buildings and their impact on a district heating system. Applied Energy, Volume 161, 1 January 2016, Pages 290–299, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2015.10.024

Manfren M., 2011: Multi-commodity network flow models for dynamic energy management – Mathematical formulation. Energy Procedia, Volume 14, 2012, Pages 1380–1385, ISSN 1876-6102, http://dx.doi.org/10.1016/j.egypro.2011.12.1105

Manfren M., Caputo P., Costa G., 2011: Paradigm shift in urban energy systems through distributed generation: Methods and models. Applied Energy, Volume 88, Issue 4, April 2011, Pages 1032–1048, http://dx.doi.org/10.1016/j.apenergy.2010.10.018

Marique A.-F., Reiter S., 2014: A simplified framework to assess the feasibility of zero-energy at the neighbourhood/community scale. Energy and Buildings, Volume 82, October 2014, Pages 114–122, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2014.07.006.

Marszal J., Heiselberg P., Bourrelle J.S., Musall E., Voss K., Sartori I., Napolitano A., 2011: Zero Energy Building – A review of definitions and calculation methodologies. Energy and Buildings, Volume 43, Issue 4, April 2011, Pages 971–979, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2010.12.022.

Mendes G., Ioakimidis C., Ferrão P., 2011: On the planning and analysis of Integrated Community Energy Systems: A review and survey of available tools. Renewable and Sustainable Energy Reviews, Volume 15, Issue 9, December 2011, Pages 4836–4854, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2011.07.067

Mickwitz P., Hildén M., Seppälä J., Melanen M., 2011: Sustainability through system transformation: lessons from Finnish efforts. Journal of Cleaner Production, Volume 19, Issue 16, November 2011, Pages 1779–1787. doi:10.1016/j.jclepro.2011.07.011

Ministry of Environment, 2010: C3 Thermal insulation in a building Regulations 2010. Status: overridden by new regulations in 2012. Available in Finnish at [accessed 28.10.2014]: http://www.ym.fi/download/noname/%7B7BF051A7-6436-4724-A1FD-7688A56FB09B%7D/102966

Ministry of Environment, 2012: D3 Energy Management in Buildings Regulations and Guidelines 2012. Available at [accessed 1.10.2014]: http://www.finlex.fi/data/normit/37188-D3-2012_Suomi.pdf (in Finnish).

Mirakyan A., De Guio R., 2013: Integrated energy planning in cities and territories: A review of methods and tools. Renewable and Sustainable Energy Reviews, Volume 22, June 2013, Pages 289–297, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2013.01.033

Mohareb E.A., Kennedy C.A., 2014: Scenarios of technology adoption towards low-carbon cities. Energy Policy, Volume 66, March 2014, Pages 685–693, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2013.10.070

Monni S., Syri S., 2011: Weekly greenhouse gas emissions of municipalities: Methods and comparisons. Energy Policy, Volume 39, Issue 9, September 2011, Pages 4755–4765. doi:10.1016/j.enpol.2011.06.051

Motiva, 2015: National Energy Efficiency Agreements. Webpage, accessed 22.10.2015. http://www.energiatehokkuus-sopimukset.fi/en/about_the_agreements/

Municipality of Kannonkoski, 2010: Land use map for the Oijänniemi area in Kannonkoski, Finland.

Neves A.R., Leal V., 2010: Energy sustainability indicators for local energy planning: Review of current practices and derivation of a new framework. Renewable and Sustainable Energy Reviews, Volume 14, Issue 9, December 2010, Pages 2723–2735. doi:10.1016/j.rser.2010.07.067

Nieminen J., 2011: Future Home for the Elderly. Conference proceedings of Sustainable Buildings 2011 in Helsinki, Finland.

Nystedt Å., Shemeikka J., Klobut K., 2006: Case analyses of heat trading between buildings connected by a district heating network. Energy Conversion and Management, Volume 47, Issue 20, December 2006, Pages 3652–3658, ISSN 0196-8904, http://dx.doi.org/10.1016/j.enconman.2006.02.030

Nystedt Å., Sepponen M., 2011: Development of a concept for ecological city planning for St. Petersburg, Russia. Conference proceedings of World Renewable Energy Congress 2011, 8–11 May 2011 in Linköping, Sweden.

Nystedt Å., Sepponen M., Teerimo S., Nummelin J., Virtanen M., Lahti P., 2010: Ecograd. A concept for ecological city planning for St. Petersburg, Russia. VTT Tiedotteita – Research Notes 2566. VTT, Espoo. 75 p. + app. 12 p. Available (accessed 2.10.2014): http://www.vtt.fi/inf/pdf/tiedotteet/2010/T2566.pdf

Nystedt Å., Sepponen M., Virtanen M., 2012: Design principles for ecological districts. In Finnish. Ekotaajaman suunnitteluperiaatteet. VTT Technology 24. VTT, Espoo. 51 p. Available (accessed 2.10.2014): http://www.vtt.fi/inf/pdf/technology/2012/T24.pdf

Osterwalder A., Pigneur Y., 2010: Business Model Generation. ISBN: 978-0470-87641-1. John Wiley & Sons, Inc, Hoboken, New Jersey.

Paiho S., Hedman Å., Abdurafikov R., Hoang H., Sepponen M., Kouhia I., Meinander M., 2013a: Energy saving potentials of Moscow apartment buildings in residential districts. Energy and Buildings 66 (2013) 706–713.

Paiho S., Palos S., Airaksinen M., Ala-Juusela M., Cao G., Heimonen I., Hoang H., Holopainen R., Knuuti A., Sepponen M., Vainio T., Vesanen T., Virtanen M., Nieminen J., 2013b: Eco-efficient solutions for China's urbanization. Guidebook. VTT Technology 105. VTT, Espoo. 176 p. Available (accessed 2.10.2014): http://www.vtt.fi/inf/pdf/technology/2013/T105.pdf

Paiho S., Hoang H., Hukkalainen M., Westerberg R., 2015: Paikallista energiaa asuinalueella. Esimerkkinä Helsingin Vartiosaari. In Finnish (Local energy supply in a residential district. Case Vartiosaari, Helsinki). VTT Technology 234. VTT, Espoo. 72 p. + app. 3 p. ISBN 978-951-38-8355-3. URN:ISBN:978-951-38-8355-3. Available [accessed 19.11.2015]: http://www.vtt.fi/inf/pdf/technology/2015/T234.pdf

Pesola A., Hagström M., Vanhanen J., 2011: Study on Distributed Energy Options in Skaftkärr Testbed. Gaia Consulting, 26.5.2011. Published by STOK, Posintra Oy. Available [accessed 17.12.2015]: http://www.posintra.fi/wp-content/uploads/2014/04/Gaian-raportti-STOKin-julkaisuna-nettisivuille-valmis.pdf

Picciariello A., Vergara C., Reneses J., Frías P., Söder L., 2015: Electricity distribution tariffs and distributed generation: Quantifying cross-subsidies from consumers to prosumers. Utilities Policy, Available online 3 November 2015, ISSN 0957-1787, http://dx.doi.org/10.1016/j.jup.2015.09.007

Pina A., Silva C., Ferrão P., 2012: The impact of demand side management strategies in the penetration of renewable energy. Energy, Volume 41, Issue 1, May 2012, pages 128–137. doi:10.1016/j.energy.2011.06.013

Porvoo, 2010: Environmental development program for the city of Porvoo. Adopted by the municipality government in 4.10.2010. Available in Finnish: http://www.porvoo.fi/easydata/customers/porvoo2/files/muut_liitetiedostot/hallinto_ja_paatoksenteko/ymparistoohjelma.pdf [accessed 21.10.2014]

Prasad Ravita D., Bansal R.C., Raturi A., 2014: Multi-faceted energy planning: A review. Renewable and Sustainable Energy Reviews, Volume 38, October 2014, Pages 686–699, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2014.07.021

Rad F.D., 2010: Application of local energy indicators in municipal energy planning: a new approach towards sustainability. ACEEE Summer Study, Asilomar (CA, USA): Lund University; 5–20 August 2010. Available: http://www.ees.energy.lth.se/fileadmin/ees/Publikationer/2010/ACEEE-2010-FDR.pdf [accessed 12.11.2015].

Radulovic F., Poveda-Villalón M., Vila-Suero D., Rodríguez-Doncel V., García-Castro R., Gómez-Pérez A., 2015: Guidelines for Linked Data generation and publication: An example in building energy consumption. Automation in Construction, Volume 57, September 2015, Pages 178–187, ISSN 0926-5805, http://dx.doi.org/10.1016/j.autcon.2015.04.002

Rathnayaka A.J. Dinusha, Potdar Vidyasagar M., Dillon T., Kuruppu S., 2015: Framework to manage multiple goals in community-based energy sharing network in smart grid. International Journal of Electrical Power & Energy Systems, Volume 73, December 2015, Pages 615–624, ISSN 0142-0615, http://dx.doi.org/10.1016/j.ijepes.2015.05.008

Sampaio H.C., Dias R.A., Perrella Balestieri J.A., 2013: Sustainable urban energy planning: The case study of a tropical city. Applied Energy, Volume 104, April 2013, Pages 924–935, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2012.12.022

Sharifi A., Murayama A., 2013: A critical review of seven selected neighborhood sustainability assessment tools. Environmental Impact Assessment Review, Volume 38, January 2013, Pages 73–87. doi:10.1016/j.eiar.2012.06.006

Sepponen M., Virtanen M., Nystedt Å., 2010: Ekotaajama project archive with case area reports. In Finnish. Webpage. Available [accessed 24.11.2015]: http://archive-fi.com/page/1289296/2013-02-01/http://www.jklinnovation.fi/default/www/jyvaskyla_innovation_oy/osaamiskeskusohjelma/energiateknologia/projektit/

Sepponen M., Hannus M., Hedman Å., Palos S., Tommis M., Basciotti D., Blöchle M., Cricchio F., Reccardo D., Mastrodonato C., Bourdeau M., Decorme R., Zarli A., Wagner M.N., Sanchez Blanco A., Bellido Zuñiga E., Pelegrin F., Pereira J., Socorro R., Buron Martinez J.L., Vlasveld J., van Beurden H., 2013a: Deliverable 3.3.1 Strategy for European-scale innovation and take-up: Drivers, Policies, Diagnostics & Gaps, Value chain & partnerships. IREEN project. Available (accessed 19.6.2013): http://www.ireenproject.eu/wp-content/uploads/2012/09/IREEN_D331_Strategy_for-European-scale_innovation_and-take-up.pdf

Sepponen M., Hannus M., Hedman Å., Tommis M., Bourdeau M., Decorme R., Zarli A., Huerva A.O., Wagner M.N., Sánchez Blanco A., Carlos J.P., Aguirre Conde M., Socorro R., Buron Martinez J.L., Vlasveld J., van Beurden H., Cricchio F., Mastrodonato C., Blöchle M., 2013b: Deliverable 3.3.2 Roadmap for European-scale innovation and take-up. IREEN (ICT roadmap for Energy Efficient Neighbourhoods) project 2011–2013. Funded by EC 7th framework programme. Project report. Available (accessed 25.9.2014): http://www.ireenproject.eu/wp-content/uploads/2012/09/IREEN-D3-3-2-IREEN-Roadmap-v2-updated.pdf

Sepponen M., Tommis M., 2013: ICT supporting energy efficiency improvements in urban and rural neighbourhoods. Conference proceedings, 8 p. Portugal SB13 Contribution of sustainable buildings to meet EU 20-20-20 Targets, Guimaâes, Portugal, 30 October – 1 November 2013. [Attached to the dissertation.]

Sepponen M., Fiès B., Raúl G.-C., 2014: ICT road map for supporting energy systems in smart cities. Conference proceedings. 40th IAHS World Congress on Housing – Sustainable Housing Construction. December 16-19, 2014, Funchal, Portugal.

Sepponen M., Grahn E., Fiès B., Cavallaro A., Weise M., 2015: Research and innovation roadmap for ICTs supporting energy systems in smart cities. Conference proceedings, pp. 181–189. Sustainable places 2015, September 16–18th, 2015 in Savona, Italy. Available [accessed 11.11.2015]: http://sustainable-places.eu/wp-content/uploads/2015/11/Proceedings-SP2015_compressed.pdf

Seppä M., 2010: Figure of plan draft of the Kyöpeli area in Multia. FCG Finnish Consulting Group.

Shemeikka J., Lylykangas K., Ketom J., Heimonen I., Pulakka S., Pylsy P., 2015: SunZEB – Plusenergiaa kaupungissa. Uusiutuvaa energiaa asumiseen ja toimistoon (in Finnish). VTT Technology 219. VTT, Espoo. Accessed 4.12.2015: http://www.vtt.fi/inf/pdf/technology/2015/T219.pdf

Soltani R., Dincer I., Rosen M.A., 2015: Thermodynamic analysis and performance assessment of an integrated heat pump system for district heating applications. Applied Thermal Engineering, Volume 89, 5 October 2015, Pages 833–842, ISSN 1359-4311, http://dx.doi.org/10.1016/j.applthermaleng.2015.06.048

Sperling K., Hvelplund F., Mathiesen B.V., 2011: Centralisation and decentralisation in strategic municipal energy planning in Denmark. Energy Policy, Volume 39, Issue 3, March 2011, Pages 1338–1351. doi:10.1016/j.enpol.2010.12.006

Stratigea A., Papadopoulou C.-A., Panagiotopoulou M., 2015: Tools and Technologies for Planning the Development of Smart Cities. Journal of Urban Technology, Vol. 22, Iss. 2, 2015, pages 43-62. DOI: 10.1080/10630732.2015.1018725

SULPU, 2003: Designing of a heat pump system. In Finnish (Lämpöpumppujärjestelmän suunnittelu). The Finnish Heat Pump Association SULPU.

Szatow A., Quezada G., Lilley B., 2012: New light on an old problem: Reflections on barriers and enablers of distributed energy. Energy Policy 43 (2012) 1–5.

Tampere, 2013: Strategy for City of Tampere 2025. City of Tampere, ISBN 978-951-609-717-9. Available in Finnish [accessed 21.10.2014]: http://www.tampere.fi/material/attachments/k/6IoZ2as0k/DK_TRE_strategia_suomi_kevyt.pdf

Thomsen K.E., Schultz J.M., Poel B., 2005: Measured performance of 12 demonstration projects – IEA Task 13 “advanced solar low energy buildings”. Energy and Buildings, Volume 37, Issue 2, February 2005, Pages 111–119, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2004.01.036

Tieva, A., Junnonen, J.-M., 2009: Proactive contracting in Finnish PPP projects. International Journal of Strategic Property Management, Vol 13, No. 3/2009, pp. 219–228.

Tsoutsos T., Drandaki M., Frantzeskaki N., Iosifidis E., Kiosses I., 2009: Sustainable energy planning by using multi-criteria analysis application in the island of Crete. Energy Policy, Volume 37, Issue 5, May 2009, Pages 1587–1600, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2008.12.011

Tuominen P., Holopainen R., Eskola L., Jokisalo J., Airaksinen M., 2014: Calculation method and tool for assessing energy consumption in the building stock. Building and Environment, 75, May, pp. 153–160. doi: 10.1016/j.buildenv.2014.02.001

van der Schoor T., Scholtens B., 2015: Power to the people: Local community initiatives and the transition to sustainable energy. Renewable and Sustainable Energy Reviews, Volume 43, March 2015, Pages 666–675, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2014.10.089

Velik R., Nicolay P., 2015: Energy management in storage-augmented, grid-connected prosumer buildings and neighborhoods using a modified simulated annealing optimization. Computers & Operations Research, Available online 20 March 2015, ISSN 0305-0548, http://dx.doi.org/10.1016/j.cor.2015.03.002

Viitanen J., Connell P., Tommis M., 2015: Creating Smart Neighborhoods: Insights from Two Low-Carbon Communities in Sheffield and Leeds, United Kingdom. Journal of Urban Technology, Vol. 22, Iss. 2, Pages 19–41. DOI: 10.1080/10630732.2014.971537

Virtanen, Mikko, Heimonen, Ismo, Sepponen Mari, 2014: Stakeholder Analysis and Questionnaire Showing the Way for the Development of Business and Service Models. Energy Procedia, 58, 2016, p. 51-57. https://doi.org/10.1016/j.egypro.2014.10.408

Wedding G.C., Crawford-Brown D., 2007: Measuring site-level success in brownfield redevelopments: A focus on sustainability and green building. Journal of Environmental Management, Volume 85, Issue 2, October 2007, Pages 483–495. doi:10.1016/j.jenvman.2006.10.018

Yamagata Y., Seya H., 2013: Simulating a future smart city: An integrated land use-energy model. Applied Energy, Volume 112, December 2013, Pages 1466–1474, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2013.01.061

Yeo I.-A., Yoon S.-H., Yee J.-J., 2013: Development of an Environment and energy Geographical Information System (E-GIS) construction model to support environmentally friendly urban planning. Applied Energy, Volume 104, April 2013, pages 723–739. doi:10.1016/j.apenergy.2012.11.053

Zaron B., Verones S., 2012: Climate change, urban energy and planning practises: Italian experiences of innovation in land management tools. Land Use Policy, Volume 32, May 2013, Pages 343–355. doi:10.1016/j.landusepol.2012.11.009

Zinck Thellufsen J., Lund H., 2015: Energy saving synergies in national energy systems. Energy Conversion and Management, Volume 103, October 2015, Pages 259–265, ISSN 0196-8904, http://dx.doi.org/10.1016/j.enconman.2015.06.052

Appendix A: Paper I: Energy saving potentials of Moscow apartment buildings in residential districts

Paiho Satu, Hedman Åsa, Abdurafikov Rinat, Hoang Ha, **Sepponen Mari**, Kouhia Ilpo, Meinander Malin. Energy and Buildings, Vol. 66, pages 706–713. Copyright 2013 Elsevier B.V. Reprinted with permission from Elsevier.
http://dx.doi.org/10.1016/j.enbuild.2013.07.084

Energy and Buildings 66 (2013) 706–713

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Energy saving potentials of Moscow apartment buildings in residential districts

Satu Paiho *, Åsa Hedman, Rinat Abdurafikov, Ha Hoang, Mari Sepponen, Ilpo Kouhia, Malin Meinander

VTT Technical Research Centre of Finland, P.O. Box 1000, FI-02044 VTT, Finland

ARTICLE INFO

Article history:
Received 13 May 2013
Accepted 30 July 2013

Keywords:
Apartment buildings
Energy savings
Building renovations

ABSTRACT

This study estimates the energy savings potentials of Moscow apartment buildings through different renovations concepts. Also the reductions of the district level energy demands resulting from the possible building level energy savings were estimated. The principles of these energy chain analyses are also described.

Most of the apartment buildings in the Soviet Union were constructed between 1960 and 1985, and as a result the urban housing stock today consists mainly of a few standard building types. Energy efficiency of buildings is typically poor. A typical residential district was selected for the analyses. The energy consumption of a typical Russian building was estimated by calculating heating of living spaces, heating of domestic hot water, and the consumption of electricity. The energy consumption of the selected building stock was based on the calculated consumptions of the type buildings. The present state of the district level was studied first, including energy chain analyses. Then the energy savings potentials for three different renovations concepts were estimated. In addition, non-technical barriers to energy efficient renovations are discussed.

1. Introduction

Energy strategy of Russia for the period up to 2030 states that Russia must improve its energy efficiency and reduce energy intensity of its economy to the level of countries with similar climatic conditions such as Canada and the Scandinavian countries [1]. In addition, it is required that Russia's living standards must correspond with those of the developed countries.

According to national statistics service the share of dilapidated and emergency-state housing is around 3% of the total area of the Russian housing stock [2]. However, it is estimated that more than 290 million m^2 or 11% of the Russian housing stock needs urgent renovation and re-equipment, 250 million m^2 or 9% should be demolished and reconstructed [3]. Some 58–60% of the country's total multi-family apartment buildings are in need of extensive capital repair [4].

In 2005; the Russian residential, public, and commercial buildings were responsible for 144.5 Mtoe (million tonnes of oil equivalent), i.e. 1680 TWh, of final energy use (34%) and for 360 Mtoe, i.e. 4186 TWh, of primary energy (55% of overall primary energy consumption). The technical energy efficiency potential of the buildings was assessed at 68.6 Mtoe, i.e. 797,820 GWh [5]. Residential buildings are evaluated to have the largest energy savings potential out of all building types. The largest part (67%) of the energy savings could be implemented through the more efficient utilization of district heating in space and water heating. An estimated 60% of the Russian district heating network is in need of major repair or replacement [6]. The investment needs for rehabilitating the district heating systems is Russia are estimated at US$ 70 billion by year 2030 [7].

The majority of Moscow housing stock is built after World War II [2] and need modernization. Sustainability should be taken to account when renovating these buildings. Thus, energy efficiency of buildings and districts is one of the core issues. Before deciding any renovation solutions, the energy consumption levels need to be estimated. After the estimation, different renovation concepts can be compared with the current situation. This paper describes the principles of the energy analysis process, estimates the present state energy consumptions of a typical Moscow apartment building and a typical district (neighbourhood), and then analyses different building level energy renovation concepts.

Often technical solutions exist for energy renovations of buildings but other obstacles hinder or delay their realization. These non-technical barriers to energy efficient renovations of Moscow residential districts are also described in this paper.

* Corresponding author. Tel.: +358 50 3315160.
E-mail address: Satu.Paiho@vtt.fi (S. Paiho).

0378-7788/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enbuild.2013.07.084

2. The Moscow housing stock

Construction in Russia [2] state that the total Russian housing stock in terms of total residential floor area was 3177 million m^2 in 2009. Total area of the housing stock per capita was 22.4 m^2.

According to the statistics from 2004, 95% of the Moscow dwelling space is built after World War II, from which 52% of the residential buildings were built during 1946–1975 and 43% in 1976 or later. According to Rosstat [2], there were 39.801 residential buildings in Moscow in 2009. The amount of residential buildings equals 3,835,000 apartments and the total floor area of 214 million m^2. The average floor area of an apartment in Moscow was 55.8 m^2 and the average number of residents per apartment was 2.8. The figures do not account for administrative expansion of Moscow implemented in summer 2012.

2.1. Typical apartment buildings in Moscow

It is important to understand the general situation in the target place before conducting energy analysis. In 2004 United Nations published Country Profiles on the Housing Sector Russian Federation [3], which helps to form an overview of typical building solutions in Moscow and in Russia. First of all, the industrialization of construction started in the Soviet Union in the 1950s, after which the precast concrete large-panel construction developed quickly. Most of the apartment buildings were constructed between 1960 and 1985, and as a result the urban housing stock today consists mainly of a few standard building types. [3]

In general, there are three basic categories for residential panel buildings [3]:

- First generation is five-storey buildings often called *khrushchevky*. Khrushchevky have been built between 1959 and 1969 and about 10% of residential buildings belong to this category. Typically their state is quite poor nowadays and they are situated in fairly attractive areas, not far from city centres.
- Second generation buildings were constructed between 1961 and 1975. The number of storeys varies but nine-storey buildings are the most common. The buildings are long and there are usually five to nine staircases in each. The external walls are different lightweight concrete structures without separate thermal insulation material. The housing norms of 1963 regulated their design and construction. The dwellings in this category are more comfortable than those in the first-generation buildings.
- Third generation buildings were built mainly after 1975 in the suburbs. Large elements and prefabricated modules were used. These buildings are nine-storey or higher, tower type blocks of flats or long, narrow buildings with four to seven staircases. The external walls are usually 32–35 cm thick expanded-clay lightweight concrete.

Natural ventilation is a typical solution in Russia [8]. District heating networks supply heat to about 80% of Russian residential buildings and about 63% of the hot water used by Russia's population [6].

Energy efficiency of these apartment buildings is typically poor. The thermal insulation of the precast panel walls does not meet modern standards, and may cause moisture and mould problems. Moreover, the surroundings like streets, courtyards and parks are usually poorly maintained. The limited variation in the urban housing stock results in suburbs of large uniformity, where individual wishes or needs are rarely met. [3]

There is one more issue that should be considered when studying Russian buildings. It is quite difficult for researchers from outside of Russia to find and correctly interpret Russian data. According to Opitz [9], the central government has a desire to conceal important production and financial facts, which means that the clarity and consistency in published statistics is often rare, and a lot of interesting information is simply unavailable to the general population. Moreover, the statistical reports published in several forms by Goskomstat (the State Committee on Statistics) were incomplete and often inconsistent. The accounting methods and definitions varied among sources and even within the same source in different years. Opitz [9] states that the data almost seem designed to confuse. The data used for this paper was gathered from several sources, and cross-checked when appropriate sources were found.

2.2. The selected housing district

A typical residential district was selected to be analyzed in the project. The selected district mostly represents 4-th Microrayon of Zelenograd, Moscow (longitude 37° east and latitude 55° north). Zelenograd is located about 35 km to the North-West from Moscow City centre. The district dimensions are approximately 1 × 0.5 km. It represents a typical residential district of Moscow and Moscow region with high-rise apartment buildings constructed for the most part in 1960s and 1970s. The district is heated with district heating. Renovation of such buildings and districts may be needed in the near future.

The apartment buildings in the area can be divided into groups according to the building series: II-57, II-49, AK-1-8, II-18 and Mr-60, which are apartment buildings build between 1966 and 1972. Each building series represents a specific building design [8]. There are also other apartment buildings, schools, kindergartens, shops, a bank in the area, but since this project concentrates on modernization of buildings, these newer buildings from the 90s and from the beginning of 2000 are excluded from these energy calculations. The more detailed data about the older apartment buildings is presented in Table 1 and these buildings were the main target of the first calculations of this study. After the initial analysis the most common building type II-18 was selected for further analyses.

In total there are approximately 13,800 residents in the buildings that are included in the calculations. The total floor area of the studied buildings is 327,600 m^2. The number of residents is estimated based on the assumption that the average occupancy rate per flat is 2.7 persons [3].

3. Principles of the energy analyses

The main objective for the energy analyses was to form an overview of average energy consumption, energy production quantities, and energy efficiency in Moscow, Russia. The energy analysis is important, because it helps to recognize the best ways of how to improve the energy efficiency of entire districts and energy systems. The key questions are: "How the energy is currently produced for buildings and districts?", "What are the most efficient ways to reduce energy consumption and how much can it be reduced?", "What is the environmental impact of energy production and how emissions caused by it can be reduced?" and "What are the life cycle energy costs of different alternatives?".

The general methodology of energy analyses is presented in Fig. 1. At first the state of the art was studied for both old apartment buildings and the entire residential district in the Moscow region. This means that the typical apartment building parameters were identified, and an example district was selected for the calculations. Most of the buildings in the example district are built between 1966 and 1972. A few different typical apartment building types was studied: their monthly energy consumption levels were calculated, and then from those results the energy demand of the entire district was calculated including also the energy demands for

Table 1
Apartment building types and their basic data in the studied district.

Description	Long apartment building	Long apartment building	Higher apartment building	Apartment building	Apartment building
Series	II-57	II-49	AK-1-8	II-18	Mr-60
Construction year	1967–1968	1966–1969	1971–1972	1965–1966	1967–1968
Number of buildings[a]	4.6	11	6	10	4
Apartments per building	358	143	102	84	111
Residents per building[b]	967	386	275	227	300
Floor area (m^2)	22,827	8951	7140	4911	8042
Number of floors	9	9	17	12	16
Shape	Rectangle	Rectangle	Rectangle	Rectangle	Rectangle
X/*Y* ratio[c]	0.07	0.16	0.40	0.60	0.38

[a] 0.6, because there is one smaller similar building.
[b] Assumption: an average flat has 2.7 residents (United Nations 2004).
[c] Shape of the building: *X* is width of the building and *Y* is length of the building.

waste and water management and street lighting. The next step was to evaluate the energy saving potentials that can be achieved with renovating these old apartment buildings. This was done by calculating different scenarios for renovated apartment buildings. As a result knowledge of total energy consumption levels in different scenarios in the typical Moscow residential district was achieved.

The last phase of the energy chain analyses is to study the energy production. This part also starts with the state of the art of the existing or typical energy production and distribution systems. Then improvements and renewal of these systems can be identified. Finally, the life cycle emissions for different energy production solutions can be calculated.

4. The state-of-the-art energy analyses

4.1. The energy consumption of buildings

The energy consumption of a typical Russian building was estimated by calculating heating of living spaces, heating of domestic hot water, and the consumption of electricity. First the current states of the selected building districts, chosen to be renovated or modernized, were analyzed by means of typical buildings. The analysis took into account structural solutions, heating, ventilation, water and drainage, electrical and other technical systems.

The energy consumption of the type buildings was calculated with WinEtana, which is a building energy analysis tool developed by VTT Technical Research Centre of Finland. The average monthly

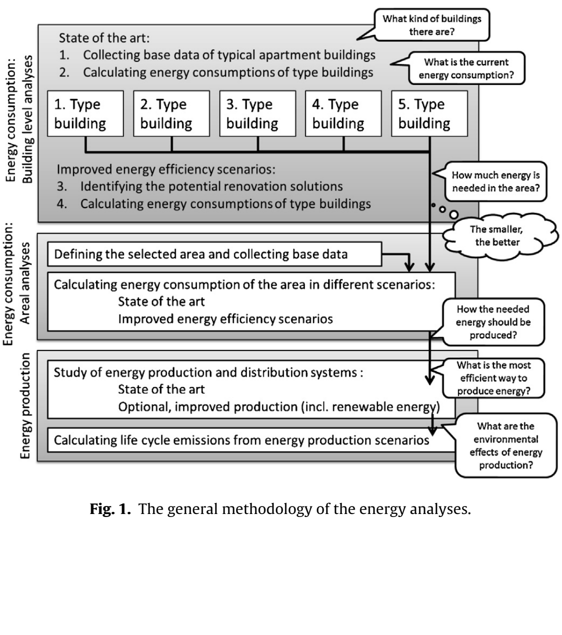


Fig. 1. The general methodology of the energy analyses.

temperatures in Moscow were adjusted in the calculation tool to get more accurate results. The temperature data of Moscow region was retrieved from the website of EnergyPlus Energy Simulation Software by U.S. Department of Energy [10].

Typical building parameters in Russia and in Moscow were used in the calculations. We used the value 18 °C in our calculations as the default indoor temperature for living spaces in multi-family buildings located within the case districts. According to Russian construction norms on thermal performance of buildings, the value of building air tightness at 50 Pa pressure difference (n50) must not exceed 2 h^{-1} for mechanical and 4 h^{-1} for natural ventilation. However, based on the results of field measurements with blower door tests [11] for a 9-storey building, which represents closest to the buildings in the case district – the average values were 7.5 h^{-1} (vents sealed) and 6 h^{-1} (vents and windows sealed). In our calculations we used a rather conservative estimate of air density factor n50, 6.5 h^{-1} so that it represented recent improvements in air tightness of windows due to massive installation of plastic-aluminium windows by residents of apartment buildings in Russia.

Natural ventilation is a typical ventilation solution in Russia [8]. Type of base floor in the buildings is assumed to be ground-supported slab. The typical *U*-values in Moscow buildings are approximately 1.1 W/m^2C° for wall constructions and 2.9 W/m^2C° for fenestration (converted from transmission R values by Matrosov et al. [12]). Opitz et al. [8] point out that the design R values differ minimally among older buildings built between 1954 and 1979, and they are essentially the same among buildings even with different wall structures (except for recently constructed buildings with 3-layes panel walls).

Because Estonia was part of the Soviet Union, there still remain numerous apartment buildings built during the Soviet era. The typical annual Estonian water consumption is between 180–290 l/capita/day [13]. We estimated that the average water consumption in the selected buildings is 272 l/capita/day, of which hot domestic water consumption is 46%, thus 126 l/capita/day). The hot water consumption is based on expert estimations and average Finnish water consumption data.

Electricity consumption of the building was estimated based on the assumed typical electrical equipment and their energy efficiency classes. It included lighting, household electrical equipment: (laundering, dish washing machine, entertainment, computer, stove, refrigerator, freezer, and other equipment), as well as outside lighting, and facility electric consumption (parking slot (preheating of cars), elevator and pumps). The average energy efficiency class of electrical equipment was assumed to be class D (typical in Finland).

As for the part of internal heat gains, the following values were used based on the experiences of Finnish experts [14]: 0.96 kWh/m^3/month from domestic hot water (30% of the heat demand [15] for hot water), 1.42 kWh/m^3/month from electrical equipment and 0.4 kWh/m^3/month from people.

Table 2
Annual energy consumptions per floor area of the type buildings in the selected district.

	Long apartment building	Long apartment building	Higher apartment building	Apartment building	Apartment building
Building series	II-57	II-49	AK-1-8	II-18	Mr-60
Space heating (kWh/a, m^2)	120	126	127	126	123
Hot domestic water (kWh/a, m^2)	88	88	88	88	88
Losses (kWh/a, m^2)	4	4	4	4	4
Total heating energy consumption (kWh/a, m^2)	212	218	219	219	216
Total electricity consumption (kWh/a, m^2)	42	45	38	47	39

The calculated energy consumptions per building floor area are presented in Table 2. According to the calculations the average heating energy consumption of typical old apartment buildings in Moscow was 217 kWh/m^2,a and the average electricity consumption 42 kWh/m^2,a. The result is quite well in line with some reference studies, e.g. [13]. The differences in energy consumption calculations may result from the divergence of the base data. Russian structures and used system solutions of buildings may vary in different buildings (even within same building series) or even within single buildings. Moreover, according to the Moscow city programme [16] "Energy Conservation in Construction in the City of Moscow During 2010–2014 and Until 2020" the thermal insulation of buildings comply with norms only 'on the paper', which may also explain the differences in results. Also the air tightness of the building has a big significance.

Since the variations of the annual heating and electricity consumptions were small, only the most common building type (II-18) in the district was chosen for the further analyses. A general picture of the energy flows going in and out of the building II-18 is presented in Fig. 2.

4.2. The district level energy consumption

The annual heating energy consumption of the most common building type II-18 (Table 2) was 219 kWh/m^2,a and the annual electricity consumption 47 kWh/m^2,a, respectively. Heat is distributed in the district through district heating network. In Russia, an estimated 20–30% of heat is lost through the heat distribution network before it reaches the end consumer [6]. So, it was assumed that the heat distribution loss in the network is 20%. The transmission losses of electricity are typically approximately 10% in Russia [17] which was also used in the calculations. Then, the total annual heating energy consumption of the apartment buildings in the selected area was 71.8 GWh/a, and the total annual electricity consumption was 15.5 GWh/a. This means that annually the buildings in the selected district need heating energy production of 89.8 GWh and electricity production of 17.2 GWh.

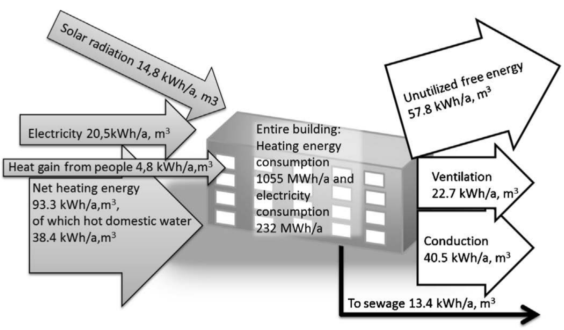


Fig. 2. The calculated energy streams of the apartment building II-18.

Energy needed for water purification was estimated to be 7 kWh of heating and 49 kWh of electricity per person in a year, and respectively 23 kWh of heating and 62 kWh of electricity for wastewater treatment [18]. Outdoor lighting was estimated to consume 350 kWh per lamp in a year, while a quote of 0,167 lamps per inhabitant was used [19,20]. Taking these into account the total annual heating energy demand without distribution losses for the district is 72.2 GWh and the total annual electricity demand without transmission losses 17.8 GWh, respectively. Adding the losses mentioned above will result in the total annual heating demand of 90.2 GWh and the total annual electricity demand of 19.5 GWh.

Heating energy in Moscow is up to 70% generated by large scale combined heat and power (CHP) plants and they are usually using natural gas [16]. Assuming that the heat and the power for the examined district are produced by a natural gas CHP plant, the related annual CO2-equivalents are for the heating 24.3×10^6 kg/a and for the electricity 9.9×10^6 kg/a (Table 7), respectively. These equal to the annual total CO_2-equivalent of 34.2×10^6 kg/a and the total per person of 2.5×10^3 kg/a/p.p. As a comparison, the heating of buildings in Finland accounted for 3.97×10^9 kg of CO_2-equivalents in 2009 which per citizen would correspond to 0.74 kg in a year. This would be less the than half of the corresponding values for case district (1.77 kg/a/p.p).

5. The energy analyses of alternative building renovation concepts

Three alternative renovation concepts were selected for closer analysis (Table 3). The cases had different values for the following characteristic: the *U*-values of building structures (outer wall, base floor, roof, windows and doors), ventilation type, air tightness factor, lighting (indoor), electricity consumption/electrical equipment and water consumption. The renovation cases are adjusted in such a way that each of them result as an improvement from a previous one when it comes to the total annual energy consumption. The basic renovation refers to minimum, low-cost or easy-to-do retrofit measures. The improved renovation solutions outputs better energy or eco efficiency. The advanced renovation column suggests the most progressive solutions. If not otherwise stated, the improved and advanced solutions always include the solutions mentioned in the previous renovation.

The annual results from the simulations are shown in Table 4, from which emerges that each case consumes less energy than the previous one. The same goes also for heat consumption while the consumption of electricity is higher for the Advanced-case in comparison with the former Improved-case. The cause of this was the change of the ventilation system to a mechanical one consuming more electricity. However, since the improved ventilation system recovered 60% of the heat of the exhaust air that otherwise would have been lost it resulted in energy savings in the end in form of heat. In Table 5, there are the results presented as percentages by comparing each value of the cases to the same value of the State of the art-case (the current case). Table 6 represents the yearly energy consumption per floor area for each of the cases.

Table 3
Building level renovation concepts. If not otherwise stated the improved and advanced concepts always include the solutions mentioned in the previous renovation.

Technology/system	Current status	Basic renovation	Improved renovation	Advanced renovation
Structures: *U*-values (W/m² K)				
•Outer walls	1.1	0.5	0.32	0.15
•Base floor	1.1	–	–	–
•Roof	1.1	0.25	0.24	0.15
•Windows and doors	2.9	1.85	1.5	1.0
Ventilation	Natural ventilation	Natural ventilation, repairing the existing system (ensuring sufficient air exchange rate) Installing outdoor valves	Enhanced mechanical exhaust	Mechanical ventilation (supply and exhaust air) with annual heat recovery efficiency 60%
Air tightness factor n50 (1/h)	6.5	4.0	2.0	
Electricity consumption/electrical equipment		Car parking places (electricity: max two hour control) Energy efficient household appliances Energy efficient lighting of staircases and public spaces	Energy efficient pumps and fans	Lifts – braking with recovering energy Demand based control of lighting of staircases and public spaces
Water consumption (l/day/occupant)	272/of which hot water 126	Installation of modern fixtures and appliances (160)	Installation of water saving fixtures and appliances (120)	Separate metering (100)

Table 4
The annual energy consumptions of the building type II-18 with different renovation cases.

	Current	Basic	Improved	Advanced
Total energy consumption (kWh)/building,a	1,308,003	840,731	675,755	518,897
Heating consumption (kWh)/building,a	1,076,373	658,288	511,189	348,027
Space heating	620,766 (58%)	388,946 (59%)	308,833 (60%)	180,245 (52%)
Domestic hot water	434,076 (40%)	256,176 (39%)	192,132 (38%)	160,104 (46%)
Losses	21,516 (2%)	13,164 (2%)	10,212 (2%)	6,936 (2%)
Electricity consumption (kWh)/building,a	231,630	183,510	172,000	190,460

Table 5
Energy consumptions of different renovation cases compared to the current.

	Current	Basic	Improved	Advanced
Total energy consumption	100%	64%	52%	40%
Heating consumption	100%	61%	47%	32%
Space heating	100%	63%	50%	29%
Domestic hot water	100%	59%	44%	37%
Electricity consumption	100%	79%	74%	82%

In Fig. 3, there is a chart of the energy consumptions of the building II-18 for different renovation cases. The total energy consumption, the heating consumption, the electricity consumption, the energy consumed for space heating, the energy consumed for domestic hot water and the energy losses of the building are shown in the figure. The total energy consumption is composed of the total heating and electricity consumptions, while the total heating consumption is a sum of the space heating and the domestic water heating. The losses curve represents efficiency based energy losses of the heating systems.

All the heating (total heating, domestic hot water, space heating) curves show a steep decrease from the state of the art to the Basic renovation-case; this has to do with the proportions in the characteristic values. The *U*-values were decreased with 65% for the outer walls, 77% for the roof and 36% for the windows from the State of the art to the Basic renovation case. The corresponding values were 36%, 4% and 19% from the Basic to the Improved renovation case and 53%, 56% and 33% from the Improved to the Advanced renovation case.

Table 6
The annual heating and electricity consumptions per floor area for each renovation case.

	Current	Basic	Improved	Advanced
Heating consumption (kWh/m²,a)	219	134	104	71
Electricity consumption (kWh/m²,a)	47	37	35	39

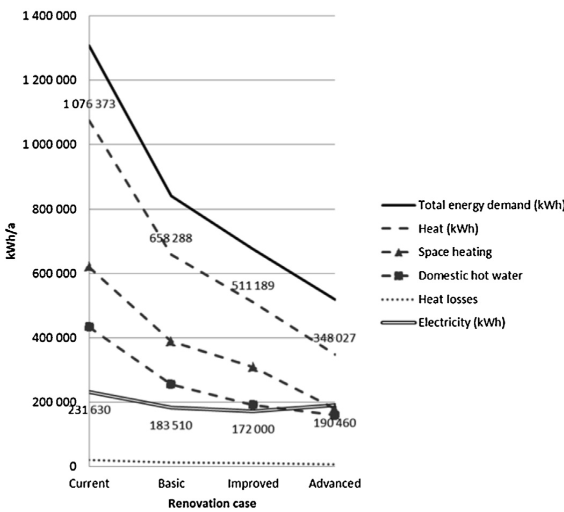


Fig. 3. Energy demand graph for the different renovation cases of the building II-18.

Table 7
CO_2-equivalents from natural gas CHP energy generation for different concepts.

	Current	Basic	Improved	Advanced
Heat (kg/a)	24,296,019	14,060,219	10,767,202	5,656,596
Electricity (kg/a)	9,913,875	7,811,025	6,851,705	6,144,183
Total (kg/a)	34,209,894	21,871,245	17,618,907	11,800,779
Total per person (kg/a/p.p)	2477	1583	1276	854

The space heating is showing a steep decrease again between the Improved- and the Advanced-case, partially because of changes in the U-value and partially since the losses are being recovered by the ventilation system (not the same losses as in Fig. 3). However, the water heating curve between the same cases is behaving oppositely which results in only a smaller change in the total heat curve.

The heat consumption for domestic water is corresponding to the amount of water consumed which is decreased with 41%, 25%, and 17% from each case to another (Current, Basic, Improved, Advanced). The electricity consumption is also the steepest between the State of the art and Basic cases, since all household appliances are changed to more energy efficient ones. Smaller improvements are being made in the energy consumption of electrical appliances between the Basic and Improved cases. The energy consumption rises between the Improved and Advanced cases due to the ventilation system even though some improvements are being made with the elevator system. However, the electricity consumption in the Advanced case does not surpass the State of the art case.

Grouping all the energy consumption together the curve is steep from the Current to the basic case, while the development is less steep and constant for the rest of the cases. What can be observed from these results is that space and water heating is consuming the larger part of the total energy. A considered amount of the consumption can therefore be reduced through improving insulation (U-values) and reducing water consumption habits. Also, heat recovery from the exhaust air is proven to be a way of saving energy significantly but results in increased electricity consumption.

In Table 7, there are listed the CO_2-equivalent greenhouse gases for different renovation concepts assuming that the energy is produced by natural gas CHP plant. Even the Basic renovation concept reduces the total CO_2-equivalents by 36%. The reduction with the Improved concept is 48% and with the Advanced concept 66%, respectively.

6. Non-technical barriers to energy efficient renovations

There are a number of obstacles that prevent Russia from benefiting from the existing potential of improved eco- and energy-efficiency in buildings. Common, well-documented ones include relatively low energy tariffs (e.g., [13,21]), higher up-front investment costs of implementing renovation solutions, as well as high interest rates [22].

The most important obstacle in building renovation in Russia is outdated norms and long permission processes [23]. The norms do not acknowledge the existence of new efficient technologies and materials. Even though the systems and materials can be relatively easily certified, the old norms are used by the authorities when checking the acceptance of a specific design solution. It may be very difficult to prove that a new type of heating system will be able to provide enough heat, or that connection capacity could be reduced because thermal insulation is improved.

Apartment-specific sub-metering is required in all buildings for electricity and hot and cold water as well as heating, although with respect to the latter these requirements have not always been fulfilled. In existing buildings water meters are not always installed by residents despite the requirement, even though the meter and installation usually pays for itself rather quickly, the resistance to install the meters most likely has to do with lack of information.

In residential buildings mechanical ventilation is neither allowed nor prohibited, and the officials in charge of issuing building permits or parties approving renovation plans refrain from assuming responsibility in the absence or clear official guidance as to how the connection capacity of space heating system should be dimensioned and mechanical ventilation systems designed, installed and maintained, even when there is an understanding that natural ventilation is less energy-efficient especially in high-rise residential buildings than a mechanical system with heat recovery.

There are differences in operation practices that should be considered when implementing an eco-efficient renovation. Often when remodelling the apartments, the owners introduce significant changes to buildings' technical systems, e.g. they seal an apartment from a ventilation channel, or even block a building's ventilation channels, install exhaust ventilation, alter a space heating system (e.g. connect under-floor heating). These often illegal changes affect the proper functioning of systems during the building's operational phase. It is strictly prohibited for a service company or inspectors to enter the apartments to check whether this kind of change was made, or even to maintain the system. The access is only possible with a decision of a court in the case when a tenant is absent or opposes the entry. A possible solution is to even at the design stage to try taking the engineering systems out of the apartments to the extent possible and providing service access from public areas.

6.1. Political and administrative obstacles

The question of the liability of the state in renovating the privatized buildings constitutes one of the political obstacles. The current legislation in this regard is ambiguous: on the one hand, there is a decision of the High Court confirming the obligation of the state to implement the repairs and provisions of the Housing Code, claiming that the residents must jointly take on all the responsibilities concerning their buildings. This question is regularly raised both by representatives of elected bodies of state power and, at a broader level, by the community, and is tool of political struggle, especially so in the election race. When citizens' law suits are filed with courts, the latter typically obligates municipal administrations to conduct the renovation of the apartment building and hencesociety expects that the state will conduct (finance) the renovations of the formerly privatized apartment buildings [24].

Given the above, it is common for municipal administrations to conceal information on the actual technical state of residential buildings in case they are declared as "dilapidated" or "dangerous" as then the administrations would have to resettle the residents and provide them with substitute housing of comparable standard at the expense of a regional budget where funds for this purpose are typically insufficient. In addition, the quality of information on the actual technical condition of buildings is typically low: for most of the buildings technical inspections to assess the actual wear of individual buildings are not conducted. Typically, the wear is estimated as a total "percentage of worn-out structures", which does not provide enough information for decision-making.

The sector of residential construction is highly dependent on administrative bodies, the system of urban planning and land use remains the source of administrative rents [22]. Most international assessments rank Russia as one of the most corrupt major economies in the world. According to Transparency International, public officials and civil servants, including the police, are seen as belonging to the most corrupt institutions in Russia, followed by the education system and parliament [25].

6.2. Social aspects

In the renovation business, social aspects are vital and need to be considered in advance. The distrust of apartment owners is the first obstacle an investor will face at the beginning of the project. A possible solution is to partner with local authorities to keep the residents informed, similar to the current budget co-funded renovation practice in Moscow and, ideally, involve the residents into the planning process. This way, different kind of rumours and disinformation of residents can be efficiently managed, despite the fact that it is common for Russians not to trust the authorities, institutions, builders, etc. This distrust is also one of the causes of passivity on the part of people in joint planning activities (e.g. public hearings of renovation projects). Therefore, the involvement of residents, openness, transparency and the possibility of the residents influencing the decision making is important for success.

In cases where the need for renovation is substantial and requires a temporary resettlement it may turn into the biggest obstacle, as agreement with each apartment owner would need to be reached [26]. Another important aspect is that income levels may vary among the residents of the same building, which complicates joint decision making on building renovation.

7. Discussion

The need to modernize and upgrade buildings in Moscow districts is evident, because only minor share of residential building stock aged over 35 years has been renovated to date. Indoor conditions are poor and the energy losses from buildings are significant. Energy efficiency improvements should be considered when upgrading the districts to benefit from opportunities to reduce energy consumption.

It is evident that there is a need for local knowhow when analysing the energy efficiency of districts in Moscow. A correct interpretation of statistics requires knowledge about Russian conditions. The analysis of buildings is eased by the fact that there are only a few building types, but on the other hand, in reality the used materials and their parameters can vary significantly also within the same building series. In this research it also turned out that the energy performances of the different building types are not differing significantly, and an adequate analysis can be made even by using only one building type.

The district heating network has a big potential for improving the energy efficiency of Moscow, because there are lots of heat losses in the heating network present day. One important renovation target is to install completely automatic individual substations in every building and so pass from the old four-pipe to new two-pipe district heating systems [27] with heat exchangers enabling control of heat distribution into buildings and apartments based on the actual heat demand. On the building level, the air tightness of the structures is one key issue that needs to be addressed in the retrofit solutions. Based on this study, the building level energy savings potential for the heating energy is up to 68% and for the electrical energy up to 30% based on these calculations. In addition, the CO_2-equivalent greenhouse gases may be reduced up to 65%.

To achieve a universally efficient energy solution in Moscow, the entire energy chain needs to be analyzed and improvements made bearing in mind the whole energy chain. The results of this study showed that improved indoor conditions and reduced heating consumption often lead to increased electricity consumption. By analysing indoor conditions energy efficiency and the building overall energy efficiency instead of energy consumption the issue of increased electricity consumption is put to correct context and the improved "output" of the consumed energy is considered properly.

The different renovation concepts were not analyzed from the economical point of view. This should also be done in order to form an understanding on what renovation solutions are feasible in Moscow apartment districts. Some solutions may also turn out unsuitable in practice. In addition, several non-technical barriers exist for renovations in Moscow. These need to be solved too in order to get progress.

Acknowledgements

The authors wish to thank the Finnish ministry of foreign affairs for funding this research.

References

[1] Ministry of Energy of the Russian Federation, Energy strategy of Russia for the period up to 2030, 2010, pp. 172, ISBN 978-5-98420-054-7 (accessed 21.01.13: http://www.energystrategy.ru/projects/docs/ES-2030_(Eng).pdf).
[2] Construction in Russia, Rosstat., 2010 (in Russian) (accessed 1.06.11: http://www.gks.ru/bgd/regl/b10_46/IssWWW.exe/Stg/05-09.htm).
[3] United Nations, Country profiles on the housing sector, Russian Federation, New York and Geneva, 2004, pp. 123, ISBN 92-1-116917-8 (accessed 10.01.13: http://www.unece.org/fileadmin/DAM/hlm/documents/2005/ECE/hbp/ECE_HBP_131.e.pdf).
[4] International Finance Corporation (IFC) & European Bank for Reconstruction and Development, Financing Capital Repairs and Energy Efficiency Improvements in Russian Multi-family Apartment Buildings, Key Conclusions and Recommendations, 2012, pp. 32 (accessed 24.01.13: http://www1.ifc.org/wps/wcm/connect/3f9bbb804cc01dfeadd0edf81ee631cc/PublicationRussiaRREP-AppartmentBuildings-2012.pdf?MOD=AJPERES).
[5] I. Bashmakov, K. Borisov, M. Dzedzichek, I. Gritsevich, A. Lunin, Resource of energy efficiency in Russia: scale, costs and benefits. CENEf—Center for Energy Efficiency, Developed for the World Bank, Moscow, 2008, pp. 102 (accessed 5.02.13: http://www.cenef.ru/file/Energy%20balances-final.pdf).
[6] The International CHP/DHC Collaborative, CHP/DH Country Profile: Russia, 2009, pp. 12 (accessed 5.02.13: http://dbdh.dk/images/uploads/pdf-abroad/IEA_Russia_16pp_A4_web.pdf).
[7] A. Nuorkivi, To the Rehabilitation Strategy of District Heating in Economies in Transition, Helsinki University of Technology, 2005, No. A13, 70 pp. +apps. 69 pp. ISBN 951-22-7542-2 (accessed 8.01.13: http://lib.tkk.fi/Diss/2005/isbn9512275422/isbn9512275422.pdf).
[8] M.W. Opitz, L.K. Norford, Y.A. Matrosov, I.N. Butovsky, Energy consumption and conservation in the Russian apartment building stock, Energy and Buildings 25 (1997) 75–92.
[9] M.W. Opitz, Potential Space-Heating Energy Efficiency Improvements in District-Heated Russian Apartment Buildings. Master's Thesis, Mechanical Engineering, University of Oklahoma (1991) and at the Massachusetts Institute of Technology (1994), 1994, pp. 200.
[10] U.S. Department of Energy, EnergyPlus Energy Simulation Software – Weather Data: All Regions: Asia WMO Region 2: Russian Federation. (accessed 5.08.11: http://apps1.eere.energy.gov/buildings/energyplus/weatherdata/6_europe_wmo_region_6/RUS_Moscow.276120_IWEC.stat)
[11] P. Armstrong, J. Dirks, L. Klevgard, Y. Matrosov, J. Olkinuora, D. Saum, Infiltration and Ventilation in Russian Multi-Family Buildings, 1996 (accessed 8.02.13: http://eec.ucdavis.edu/ACEEE/1994-96/1996/VOL01/031.PDF).
[12] Y. Matrosov, L. Norford, M. Opitz, I. Butovsky, Standards for heating energy use in Russian buildings: a review and a report of recent progress, Energy and Buildings 25 (1997) 207–222.
[13] The World Bank & IFC (International Finance Corporation), Energy Efficiency in Russia: Untapped Reserves, 2008, pp. 134 (accessed 22.01.13: http://www1.ifc.org/wps/wcm/connect/400e24004b5f69148d21bd6eac26e1c2/Final_EE_report_engl.pdf?MOD=AJPERES).
[14] J. Shemeikka, Discussions with the WinEtana software developer at VTT, 2011.
[15] M. Nyman, P. Hoving, K. Klobut, R. Kosonen, J. Laine, J. Määttä, Hansa Renovation HARE 94-96, Teolliset korjaustekniikat ja mallisuunnitelmat – 5.1. Talotekniikka ja Energiakorjaukset. VTT Rakennustekniikka & RTT Rakennustuoteteollisuus 30.1.1995, 1995, 109 p. + app. (in Finnish).
[16] City of Moscow, 2009. The City programme "energy conservation in construction in the City of Moscow during 2010–2014 and until 2020". Decree of Moscow government from June 9, 2009 N536 (version from October 10th, 2010) (accessed 14.08011: http://base.consultant.ru/cons/cgi/online.cgi?req=doc;base=MLAW;n=120043)
[17] IEA – International Energy Agency, Electricity/Heat in Russian Federation in 2008, 2008 (accessed 26.09.11: http://www.iea.org/stats/).
[18] T. Tukiainen, Greenhouse Gas Emissions of Finnish Water and Wastewater Utilities. Master's thesis, Helsinki University of Technology, Faculty of Engineering and Architecture, 2009, pp. 150 (in Finnish) (accessed 14.01.13: http://civil.aalto.fi/fi/tutkimus/vesi/opinnaytteet/tukiainen2009.pdf).
[19] Echelon, Monitored Outdoor Lighting: Market, Challenge, Solutions and Next steps, 2007, pp. 19 (accessed 30.1009: http://www.echelon.com/support/documentation/papers/EchelonCorporation_StreetlightWhitepaper.pdf).

[20] M. Radocha, B. Baumgartner, Energy efficiency in streetlighting and transport infrastructure, Reference material for competence, 2006 (accessed 30.10.09: http://www.transportlearning.net/docs/Competence_reference%20material_urbandesign_en.pdf).
[21] A. Korppoo, N. Korobova, Modernizing residential heating in Russia: End-use practices, legal developments, and future prospectives, Energy Policy 42 (2012) 213–320.
[22] Russian Ministry of Regional Development, The state programme "On affordable and comfortable housing and communal services for citizens of the Russian Federation", 2013 (in Russian), 2012 (accessed on 8.02.13 http://minregion.ru/upload/documents/2013/02/8881010213-progr-5.pdf).
[23] Institute of Urban Economics, Administrative obstacles to implementation of construction projects (in Russian), 2012 (accessed 8.02.13: http://www.urbaneconomics.ru/download.php?dl_id=3715).
[24] EBRD - The European Bank for Reconstruction and Development, Russian Urban Housing Energy Efficiency Programme – Model Development, 2011 (accessed 8.02.13: http://www.ebrd.com/downloads/sector/sei/report2.pdf).
[25] World Economic Forum, Scenarios for the Russian Federation, 2013 January, pp. 18 (accessed 8.02.13: http://www3.weforum.org/docs/WEF_Scenarios_RussianFederation_Report_2013.pdf).
[26] S. Paiho, R. Abdurafikov, Å. Hedman, H. Hoang, I. Kouhia, M. Meinander, M. Sepponen, Energy-efficient renovation of Moscow apartment buildings and residential districts, VTT Technology 82, VTT, Espoo, 2013, 114 p.+app. 5 p., ISBN 978-951-38-7921-1 (accessed 28.04.13: http://www.vtt.fi/inf/pdf/technology/2013/T82.pdf).
[27] K. Eliseev, District heating systems in Finland and Russia, Mikkeli University of Applied Science, 2011, pp. 39, Bachelor's thesisa (accessed 8.01.13: http://publications.theseus.fi/bitstream/handle/10024/25777/DISTRICT_HEATING_SYSTEMS_IN_FINLAND_AND_RUSSIA.pdf?sequence=1).

Appendix B: Paper II: Energy and emission analyses of renovation scenarios of a Moscow residential district

Paiho Satu, Hoang Ha, Hedman Åsa, Abdurafikov Rinat, **Sepponen Mari**, Meinander Malin. Energy and Buildings, Vol. 76, pages 402–413.
http://dx.doi.org/10.1016/j.enbuild.2014.03.014

Energy and Buildings 76 (2014) 402–413

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Energy and emission analyses of renovation scenarios of a Moscow residential district

Satu Paiho*, Ha Hoang, Åsa Hedman, Rinat Abdurafikov, Mari Sepponen, Malin Meinander

VTT Technical Research Centre of Finland, P.O. Box 1000, FI-02044 VTT, Finland

ARTICLE INFO

Article history:
Received 28 October 2013
Received in revised form 3 March 2014
Accepted 5 March 2014
Available online 15 March 2014

Keywords:
Residential districts
Energy and emission analyses
Renovation scenarios

ABSTRACT

Three building level renovation concepts of a typical Moscow residential district are defined and their energy saving potentials evaluated in a recently published study [1]. This study extends these analyses and concentrates on energy and emission analyses of different energy renovation solutions and energy production alternatives at the district level using the same case district as in the previous study [1].

At the district level, four different energy renovation scenarios, called Current, Basic, Improved and Advanced, were analyzed in terms of energy demand and emissions. Considerable energy savings could be achieved, up to 34% of the electricity demand and up to 72% of the heating demand, using different district modernization scenarios.

As for the emission analyses, switching from natural gas to biogas would result in decreasing greenhouse gas emissions, but increasing generation of SO_2-equivalent and particulate emissions. A better solution would be to still switch to biogas while maximizing renewable energy production from local non-combustion technologies at the same time.

1. Introduction

In Russia, climate change causes environmental, economic and social stress, why a future reduction in energy consumption could benefit the national economy [2]. In an energy-inefficient country like Russia, there is the potential to weaken the link between GHG (Greenhouse Gas) emissions and economic growth by improving energy efficiency [3]. Ever since the year 2000, Russia's economy has witnessed an upswing, and the government has started to take effective measures to curb energy intensity and reduce CO_2 emissions [4].

Energy efficient renovation increases the value of a building [5]. Improved cost-effectiveness of energy efficiency measures is achieved when they are implemented as part of a building renovation. It is often important to examine the impacts of building level renovation solutions in a wider perspective, since energy renovations reduce the energy demand from the grid or network [6], as well as the primary energy consumption. Greater overall energy efficiency can often be achieved through a district-scale building and district infrastructure renovation. The renovation of buildings should not be separated from the improvement of the surrounding environment. If the surrounding environment is improved, the market value of the land will considerably increase and the area will become much more attractive to investors. Therefore, it is clear that the renovation of a neighbourhood should not be restricted to the renewal of buildings, but should be extended to the whole region [7].

Some general principles for improving energy-efficiency at the district level include: improving the energy-efficiency of buildings, outdoor lighting, energy networks and grids (especially by reducing distribution losses), replacing fossil fuels with renewable energy sources, improving the energy-efficiency of waste and water management systems, reduction of emissions (e.g. change of fuel or flue gas treatment), and energy-efficient transportation [8]. Modernization must follow the urban structure which reflects the principles of sustainable development and corresponds to the quality of life: compactness, multifunctional use of territories, sustainable transport, ensured public interests and visually attractive (unpolluted) environment [9]. Outdoor amenities, i.e. pedestrian and bicycle paths, parking lots, children's playgrounds, sports grounds, benches, litterbins, street lamps, etc., should be renovated and rebuilt because the quality of housing largely depends on them [7].

Paiho et al. [1] present three different renovation concepts for apartment buildings in a Moscow residential district. The energy consumption of a typical Russian apartment building was

* Corresponding author. Tel.: +358 50 3315160.
E-mail address: Satu.Paiho@vtt.fi (S. Paiho).

http://dx.doi.org/10.1016/j.enbuild.2014.03.014
0378-7788/

estimated by taking into account heating of living spaces, heating of domestic hot water, and the electricity consumption. The energy consumption of the selected building stock was thereafter calculated based on the estimated consumptions of the type buildings. First the present state of the district level was studied, including energy chain analyses. The energy saving potentials for the three different building level renovations concepts were thereafter estimated. Results from the calculations showed that the building level energy saving potential could be up to 68% for heating energy and 26% for electricity, respectively.

The energy analyses are continued further in this paper by looking at three district level energy renovation concepts. In combination with this, the paper introduces different energy production scenarios and estimates the annual emissions for each examined case. The purpose was to assess how low emission values could be achieved by comparing and combining technologies for energy generation, and clarify which of the combinations presented would be better in terms of produced emissions.

This study tested the hypothesis that energy renovations are more efficient at a district level than on a building level, thus including the whole energy chain from production to consumption and taking into consideration not only building scale renovations, but also improvements on the energy supply systems. Furthermore, this study aims to explore whether emissions to air correlate with energy efficiency.

2. Background

It is estimated that more than 290 million m^2 or 11% of the Russian housing stock needs urgent renovation and re-equipment, 250 million m^2 or 9% should be demolished and reconstructed [10]. Some 58–60% of the country's total multi-family apartment buildings are in need of extensive capital repair, rising to 93–95% in those apartment blocks with an average age of less than 25 years [11].

The energy strategy of Russia for the period up to 2030 [12] states that one main problem in heat supply is the unsatisfactory state of heat supply systems characterized by high depreciation of fixed assets, especially of heat supply networks and boiler rooms, insufficient reliability of operation, large energy losses and negative impact onto the environment. The high level of technical abrasion and a low level of investments into modernization of the Russian energy industry cause huge energy wastage and carbon emissions [13]. With the exception of hydropower, Russia's utilization of renewable energy sources remains low relative to its consumption of fossil fuels [14]. In the absence of a clearly formulated long-term strategy for bioenergy and renewable energy, the legal and political processes in this field have been fragmented and weak [15].

2.1. Literature review

There is no relevant literature related to the energy consumption of Russian buildings. Also nothing has been found on the impacts of different options for energy renovations of residential buildings or districts in Russia. Furthermore, no studies have been found, taking into account the different emissions of energy production types when analysing the whole energy chain from production to consumption in residential buildings.

Studies on the energy consumption of Russian buildings have been made in the 1990s by Matrosov et al. in 1994 [16] and Opitz et al. in 1997 [17]. More recent studies on energy consumption analyses of buildings elsewhere than Russia have been made by e.g. Balaras et al. in 2005 [18] (heating energy consumption of European residential buildings); Choi et al. in 2012 [19] (comparison of energy consumption according to building shape and utilization) as well as Kyrö et al. in 2011 [20] and Kim et al. in 2011 [21] (the impacts of residents' behaviour on building's energy consumption). Studies on the reduction of buildings' energy consumption through renovations have been published by e.g. Tommerup and Svendsen in 2006 [22] (energy-saving potential of Danish dwellings through energy-saving renovations), Ouyang et al. in 2009 [23] (life cycle cost analysis for energy-saving renovations of residential buildings) and Siller et al. in 2007 [24] (on reducing energy consumption and greenhouse gas emissions of the building stock through renovations).

The first study on reduction of energy consumption through district renovations was published by Oujang et al. in 2008 [25]. This paper represents the Hot Summer and Cold Winter Region of China and examines buildings which are at least seven years old and are becoming dilapidated. Opposite to the study in China, where even quite new buildings are typically demolished and new constructed [25]; the situation is different in Russia where the designed life time of buildings is significantly longer.

2.2. Moscow residential districts

As of 2012 the need for renovations was estimated at 108 million m^2 (over a half of the total floor area) in 26.3 thousands of Moscow apartment buildings based on their age [26]. From an architectural perspective, residential areas with typical apartment houses look monotonous, lack vitality and are less aesthetically pleasing [9].

In the Russian Federation, most of the apartment buildings were constructed between 1960 and 1985 during the Soviet-era, and as a result the urban housing stock today consists mainly of a few standard building types [10]. Each building series represents a specific building design [9,17,27]. Correspondingly, residential districts in Moscow have been built with only a few building types. Examples of these building types are clearly defined for example in [1,10,27]. Therefore the energy demand of the whole district can be estimated by using these building types and multiplying their performance with the number of buildings in the area.

In these buildings natural ventilation is dominating. Almost no buildings have mechanical ventilation [28,29]. Changing the inner layout of panel houses is hardly possible because the spacing between the external and internal bearing walls is small [7,9].

Energy efficiency of these apartment buildings is typically poor [10]. The thermal insulation of the precast panel walls does not meet modern standards. District heating networks supply heat to about 80% of Russian residential buildings and about 63% of the hot water used by Russia's population [30].

2.3. The selected housing district

The selected district mostly represents 4-th Microrayon of Zelenograd, Moscow (longitude 37° east and latitude 55° north). Zelenograd is located about 35 km to the North-West from Moscow City centre. The district dimensions are approximately 1 km × 0.5 km. It represents a typical residential district of Moscow and Moscow region with high-rise apartment buildings constructed for the most part in 1960's and 1970's. The district is heated with district heating. Renovation of such buildings and districts is needed in the near future.

The apartment buildings in the area are built between 1966 and 1972. After the initial analysis the most common building type II-18 was selected to represent the average building in further studies since a comparison of the demands of the buildings showed only minor differences [1]. There are also a few other newer buildings but since these analyses concentrated on modernization of buildings, these newer buildings are excluded from the studies.

In total there are approximately 13 800 residents in the buildings that are included in the calculations which is about 0.12% of

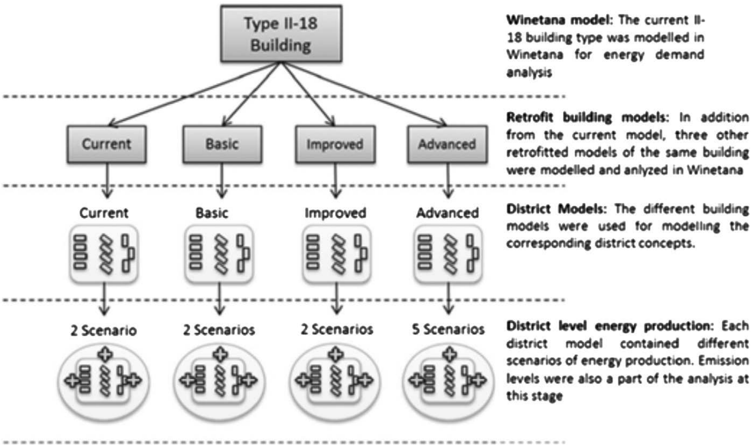


Fig. 1. Overview of the energy analysis process in this study (WinEtana is a computer software for making building energy analyses developed by VTT Technical Research Centre of Finland).

the total population of Moscow. The total floor area of the studied buildings is 327 600 m^2 and the total roof area 31,230 m^2. The number of residents is estimated based on the assumption that the average occupancy rate per flat is 2.7 persons [10].

3. Methodology

The principles of the energy chain analyses used are discussed in [1]. At first the present state was studied by selecting both a typical old apartment building and an entire residential district in the Moscow region for the calculations. The renovation concepts were assessed from the perspective of energy demand and associated environmental impacts. The assessment started with development of a "Current" energy and water demand model of the most common building type (II-18) which represented an average apartment building. From this model, other renovation models were generated. The four models where named according to the concept on which they were based: Current, Basic, Improved and Advanced.

In this study, the building models were used in the energy demand analyses of their corresponding district concepts, also named Current, Basic, Improved and Advanced. Each district concept was further used to examine different scenarios of energy production and the resulting environmental impacts. See Fig. 1 for further clarification of the different steps of the energy analysis process.

The renovation concepts and energy production scenarios were selected based on expert experience from field studies of energy efficient renovations in Finland. These were adjusted to Russian conditions also taken into account the existing Moscow building codes for new construction. Relevant detailed building codes, standards etc. do not exist for renovation. The opportunity to utilize renewable energy production was also emphasized.

The scenarios were selected primarily with the view on practical implementation of building renovations as follows: (i) only restoration of buildings to initial condition, (ii) restoration of buildings using nowadays materials available on the market, which properties have improved over the past 40 years, (iii) significant improvement of buildings to meet local requirements to new construction, and (iv) improvement of buildings going beyond the local requirements to new buildings but being "normal" to renovation projects in Finland and Northern Europe.

After the energy demands were analyzed, the life cycle emissions for different energy production scenarios were calculated. CO_2-equivalents, SO_2-equivalents, TOPP-equivalents (tropospheric ozone precursor potential) and particulates were selected to represent the environmental impact of the energy production alternatives. *CO_2-equivalent* emission is a total measure, in which the emissions of different greenhouse gases are summed up according their global warming potential (GWP) factor [31]. *SO_2-equivalent* signifies the total acidification potential, which is the result of aggregating acid air emissions [31]. In the calculation of SO_2-equivalent emissions, the utilized software GEMIS (Global Emission Model for Integrated Systems software) [32] includes SO_2, NO_x, HF, HCl, H_2S and NH_3. *TOPP-equivalent* signifies tropospheric ozone precursor potential [31]. It is the mass-based equivalent of the ozone formation rate from precursors, measured as ozone precursor equivalents. The TOPP represents the potentially formation of near-ground (tropospheric) O_3 which can cause smog. TOPP includes emissions of NO_x, NMVOC (non-methane volatile organic compounds), CO and CH_4 [31]. *Particulates* have a significant effect on the local air quality level [33].

Table 1
Corresponding emissions for heat and electricity generation based on the partial substitution method for a 1 heat/0.85 electricity for natural gas CHP plant, a 1.5 heat/1 electricity for biogas CHP plant and a 1 heat/0.345 electricity for waste incineration CHP plant.

Emissions into air	Heat for natural gas CHP (kg/MWh)	Electricity for natural gas CHP (kg/MWh)	Heat for biogas CHP (kg/MWh)	Electricity for biogas CHP (kg/MWh)	Heat for waste incineration CHP (kg/MWh)	Electricity for waste incineration CHP (kg/MWh)
SO_2 equivalent	0.59	1.2	1.3	2.0	0.4	0.3
TOPP equivalent	1.3	2.6	0.63	0.97	0.68	0.54
Particulates	0.024	0.047	0.053	0.081	0.006	0.004
Greenhouse gases						
CO_2 equivalent	285	559	26	40	36	29

3.1. Emissions calculation

The values for emissions per produced energy (kg/MWh) were retrieved from GEMIS [32] and account for the life cycle of the facility by which the energy is generated. In all, emission values were retrieved for electricity bought from the Russian grid, natural gas combined heat and power plants (CHP), (building integrated) solar photovoltaic (PV), solar collectors, wind farms (WF), Ground source heat pumps (GSHP), biogas CHP plants, natural gas boilers and biogas boilers with flue gas cleaning.

The emission values for the natural gas and biogas CHPs needed to be divided into the proportions for heat and electricity generated. This was done by the *partial substitution method*, where the idea is to split the emissions into equal parts for the heat/electricity quote in relation to the efficiency of the type of energy generated. For this, the following formulas were used:

$$\varepsilon'_{hi} = \frac{E_h}{n_h} \tag{1}$$

$$\varepsilon_{hi} = \frac{\varepsilon'_{hi}}{\varepsilon'_{hi} + \varepsilon'_{ei}} \times \varepsilon_i \tag{2}$$

$$\varepsilon'_{ei} = \frac{E_e}{n_e} \tag{3}$$

$$\varepsilon_{ei} = \frac{\varepsilon'_{ei}}{\varepsilon'_{hi} + \varepsilon'_{ei}} \times \varepsilon_i \tag{4}$$

In equation 1, ε'_{hi} denotes the heat energy to efficiency quotient where E_h is the share of heat generated (in combined heat and power), and n_h the efficiency of the heat generation. The corresponding denotations for electricity generation are shown in Eq. (3). In Eq. (2), ε_{hi} represents the partial share of a certain emission type i per produced heat while ε_i is the reference value for the same emission type (Table 1). The corresponding value for the partial fraction of a certain emission type coming from electricity generation is calculated according to Eq. (4).

The ε_i emission values for natural gas was retrieved for a 1/0.85 (E_h/E_e) heat to electricity quote and 0.9/0.39 (n_h/n_e) heat to electricity efficiency CHP plant in GEMIS. The corresponding values were retrieved for a biogas CHP plant with 1.5/1 (E_h/E_e) and 0.9/0.39 (n_h/n_e), and for a waste incineration CHP plant 1/0.345 (E_h/E_e) and 0.9/0.39 (n_h/n_e). The results for the partial fractions of emission for heat and electricity of both of the CHP plants types can be found in Table 1. Values for the other energy technologies are found in Table 2. The emissions were thereby calculated by multiplying the energy produced by the emission factors of the corresponding energy system (and the partial share of heat and electricity in cases for CHP plants) as in (5).

$$\text{Generated emissions} = \text{Amount of energy produced } (\varepsilon) \times \text{emissions per unit of energy for specific energy production (GEMIS)} \tag{5}$$

4. Energy and emission analyses

4.1. Energy analyses

The energy demands of several renovated district concepts were analyzed and compared to that of the Current concept. Each of the proposed Current, Basic, Improved and Advanced districts contained buildings with the corresponding level of renovation and additionally the improvements suggested in Table 3.

In the Current district, the annual energy demands per floor area were 219 kWh/m^2,a and 47.2 kWh/m^2,a for heating and

Table 2
Emission coefficients according to produced energy for the different types of facilities or technologies.

Emissions (kg/MWh) [32]	Russia electricity 0-level; IEA numbers	Natural gas CHP plant, 1 heat/0,85 electricity (MWh)	Solar photo-voltaic (PV)	Wind farm (WF)	Solar Thermal Heat (STH)	Ground source heat pump (GSHP), COP 3	Biogas CHP, 1.5 heat/1 electricity (MWh)	Boiler Natural gas
Emissions into air								
SO_2-equivalent (kg/MWh)	3.7	1.8	0.18	0.067	0.20	0.015	3.3	0.30
TOPP-equivalent (kg/MWh)	2.3	3.9	0.16	0.090	0.18	0.018	1.6	0.58
Particulates	0.49	0.072	0.026	0.015	0.041	0.0027	0.13	0.018
Greenhouse gases								
CO_2-equivalent (kg/MWh)	552	845	110	28	37	4.6	65	387

Table 3
District level renovation concepts compared to the current status. If not otherwise stated the improved and advanced solutions always include the solutions mentioned in the previous renovation.

Technology/system	Current status	Basic renovation	Improved renovation	Advanced renovation
Energy production	Energy produced in large-scale plants, mainly using natural gas.	Increasing energy-efficiency of energy generation processes	Reduction of emissions (e.g. change of fuel, or flue gas treatments).	Replacing fossil fuels with renewable energy sources (fuel cells, photovoltaic panels, heat pumps, etc.) and/or increasing plants' efficiency, e.g. increasing the share of CHP plants
District heating network (Heat losses, substations, flow/energy adjustment/control)	Poor controlling High distribution losses	Replacing of distribution pipes (thus reducing distribution losses of district heating) Adding building-level substations and flow control valves		Heat generation plant is capable of adjusting production according to the variable heat energy demand. Heating network able to buy excess heat production from buildings, so called heat trading (for example excess solar heat production).
Electricity distribution	Electricity distribution networks design does not allow to feed locally produced electricity to the grid, one-way flow. In some cases networks operate close to their limits, low power factor possible, old equipment (e.g. transformers)	Replacement of old equipment and cables, power factor and harmonics compensation where necessary		The basic scenario & review of automation systems to allow for connection of distributed generation. Smart metres (in case of demand response and local controllable energy generation)
Lighting (outdoor)		Energy-efficient street lighting	Street lighting designed to avoid light pollution	Smart outdoor lighting (sensor driven), street lighting electrified with solar PV's.
Water purification and distribution waste water collection and treatment	Drinking water not safe. High leakage rate in water and sewer networks. Improvement of sewage treatment efficiency where needed	Improved water purification technology. Refurbishment of water and sewer networks		Smart water network Block scale purification and treatment (to ensure safe local potable water and wastewater treatment)
Waste	Mixed waste collection >60% municipal solid waste (MSW) landfilled (27% incinerated, 10% recycled)			Increased recycling and energy utilization: ~22% municipal solid waste (MSW) landfilled (24% incinerated, 54% recycled)
Flexible/multifunctional use of spaces Dense city planning Transportation	Services are placed in nearby resident buildings which reduces transportation needs. City structure is rather dense.	Safe cycle parking facilities at train and metro stations. Cycle lending system (bike pools)	Improved cycle routes, separating cycles from cars and pedestrians. Improved public transportation.	Charging points for electrical vehicles. Charging points with embedded PV panels.

electricity, respectively [1]. The heating demand of the buildings was estimated to be fully covered by district heating with 20% heat distribution losses [30], while transfer losses of the electrical grid were estimated to be 10% [34]. Energy needed for water purification was estimated to be 7 kWh of heating and 49 kWh of electricity per person in a year, and respectively 23 kWh of heating and 62 kWh of electricity for wastewater treatment [35]. Outdoor lighting was estimated to consume 350 kWh per lamp per annum, while a factor of 0.167 lamps per inhabitant was used [15,36].

The Basic district consisted of buildings where the annual calculated demand of heating was 134 kWh/m^2, a and of electricity was 37 kWh/m^2,a. Distribution losses of the district heating network were reduced to 15% by system improvements, while transfer losses of the electrical grid remain the same as in the Current district. The energy demand for water and wastewater treatment was reduced by 36% and outdoor lighting by 50% from the previous concept.

For the Improved district, each square metre of floor area was calculated to require 104 kWh/m^2,a of heating and 33 kWh/m^2,a of electricity on an annual basis. The losses of the district heating network and the electrical grid were kept to the same as in the Basic district. The energy needed for water and wastewater treatment was 48% less than for the Current district, while the outdoor lighting electricity demand was reduced by 70%.

The advanced district was not only a further improvement on the previous district in terms of energy demand. It was further used in several scenarios for energy generation from various combinations of renewable energy sources. These alternatives will be discussed further in the emission analyses. The annual energy demands per square metre of floor area in the Advanced district

Table 4
Resulting annual energy demand for the district concepts (MWh/a).

	Current		Basic		Improved		Advanced	
	Electricity	Heat	Electricity	Heat	Electricity	Heat	Electricity	Heat
Buildings	17 168	89 753	13 495	51 691	12 125	40 194	11 899	24 963
Street lights	806		403		242		242	
Water and wastewater treatment	1533	414	981	265	797	215	675	182
Total	19 507	90 167	14 879	51 957	13 164	40 410	12 816	25 146

Table 5
Analyzed energy production scenarios for the different district concepts.

	Current	Basic	Improved	Advanced
CHP natural gas	x	x	x	x
CHP biogas	x	x	x	x
A3 scenario: solar panels, ground source heat pumps, electricity from grid				x
A4 scenario: solar panels, ground source heat pumps, electricity from wind farms				x
A5 scenario: solar collectors, solar panels, ground source heat pumps, electricity from wind farms				x

were 71 kWh/m^2,a and 35 kWh/m^2,a for heating and electricity, respectively. An exception of the Advanced district from the others is that smart metres are used in the buildings, which lowers their electricity demand by 5% (estimation based on [37]). Distribution losses of the district heating network were estimated at 7% (which is a typical level in Nordic countries), while transfer losses of the electricity grid were reduced to 9%. Energy demand for water purification and wastewater treatment is now reduced by 56% from the Current district, while electricity needed for outdoor lighting was 70% less.

The data for distribution losses of the district heating network and the transfer losses from the electrical grid used in the models were derived from [34,38]. Radocha and Baumgartner [36] and Echelon [39] were consulted for estimating electricity consumption of the different district concepts. Corresponding values for water and wastewater consumption have been obtained from [27,40].

Calculations show that the energy need is mainly affected in the Basic and Advanced concepts. This has mostly to do with the fact that the buildings are accounting for close to all the energy demand of the case district. The calculation results are shown in Table 4 where the energy demand of the district has been categorized into buildings, outdoor lighting, and water and wastewater treatment. Transfer and other losses have been accounted for in the numbers presented. Looking at electricity and heating demand separately, it is notable that the potential for reduction is 34% and 72%, respectively.

It has to be noted that transportation or other services resulting in further energy demand were not accounted for in the district energy analyses that have been carried out. These usually form a significant share of the total energy consumption in a district but were left outside the scope of the analyses where the focus was on buildings and infrastructure. Also, some of the improvements presented in Table 3 are directly related to pollution or the comfort level of the inhabitants, and would not be notable in the results from the energy.

4.2. Emission analyses

All the concepts presented were further extended with different scenarios of how the energy needed is either being acquired or produced within the area and the amount of emissions that this would result in. As shown in Fig. 1, altogether 11 district energy production scenarios were analyzed. All the district concepts had two scenarios, except the Advanced, which had five in total.

Since almost all energy produced in the Moscow area comes from natural gas [41], the scenario of heat and energy production from natural gas (Nat) was created for each district type. To evaluate the opportunity for using renewable energy, a scenario where natural gas is being replaced by biogas (Bio) was additionally examined for each scenario. Table 5 summarizes the scenarios analyzed.

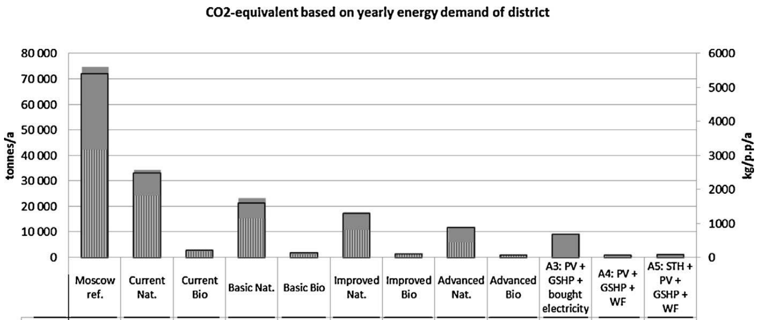
For the Advanced district concept the A3, A4 and A5 scenarios involving renewable energy were created in addition to the natural and biogas scenarios. In the A3 scenario, solar panels (PV) mounted on the roofs of the buildings was calculated to cover 7.5% of the total electricity demand, while the rest would be bought from the Moscow grid. All the heating needed would in this scenario be provided by ground source heat pumps (GSHP), which on the other hand would consume a considerable amount of electricity. The A4 scenario differed from the A3 in the way that all grid electricity was bought from a wind farm (WF). In addition to the A4 scenario, 30% of the energy needed for domestic hot water in the district was produced by solar thermal collectors (STH) in scenario A5. This would eventually lead to fewer boreholes and less electricity needed for ground source heating.

4.2.1. Emissions for the Current district

The reference emissions of the Current district (Moscow Ref.) were calculated using the equivalent values for the whole Moscow multiplied by the number of inhabitants in the selected district. Heating energy in Moscow is up to 70% generated by large scale combined heat and power (CHP) plants, 5% by small scale CHP plants and 25% by heat only boilers (HOB) [42]. This corresponds to 79.290 GWh of heat generated by the large scale CHP plants, 5.664 GWh from the small scale CHP plants and 28.318 GWh from the heat only boilers. The fuels used in large scale CHP plants are 98% natural gas, 1.4% coal and 0.6% heavy fuel oil. The fuel used in both small scales CHP plants and HOBs is 100% natural gas [42]. The fuels were in the calculations presumed to be 100% natural gas since the share of coal and heavy fuel oil was considered to be insignificantly small in comparison to the total. The total electricity production corresponding to the consumption in the city[1] was split into 45.045 GWh produced at large-scale CHP plants and 3.234 GWh produced at small-scale CHP plants. The emission values for the Moscow reference case were calculated based on this data.

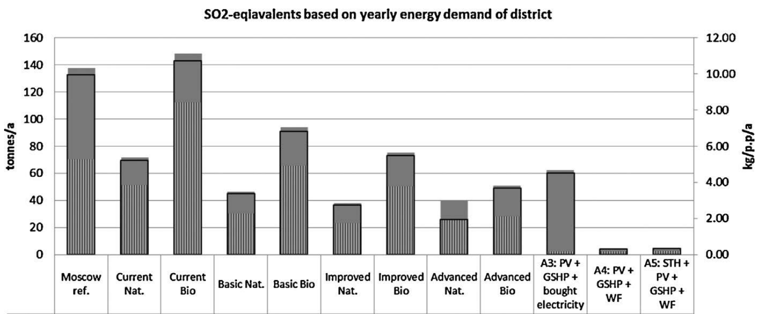
Based on the calculated energy demands (Table 4) the emissions for the Current district were calculated both for the existing natural

[1] The City of Moscow is characterized by a surplus electricity balance, i.e. more electricity is produced than it is consumed and the excess is exported to the surrounding Moscow region.



	Moscow ref.	Current Nat.	Current Bio	Basic Nat.	Basic Bio	Improved Nat.	Improved Bio	Advanced Nat.	Advanced Bio	A3: PV + GSHP + bought electricity	A4: PV + GSHP + WF	A5: STH + PV + GSHP + WF
Elec	32440.07	9913.87	725.61	7837.35	583.34	6878.03	510.90	6196.83	487.19	9026.98	683.26	653.18
Heat	42259.08	24296.02	2278.04	15328.07	1156.41	10863.04	1066.75	5848.27	701.74	282.01	282.01	385.42
kg/p.p	5407.89	2476.64	217.45	1592.22	140.62	1284.37	105.37	872.01	68.39	673.93	69.88	75.19

Fig. 2. CO_2-equivalent emissions of the district energy production scenarios.



	Moscow ref.	Current Nat.	Current Bio	Basic Nat.	Basic Bio	Improved Nat.	Improved Bio	Advanced Nat.	Advanced Bio	A3: PV + GSHP + bought electricity	A4: PV + GSHP + WF	A5: STH + PV + GSHP + WF
Elec	67.30	20.78	35.97	16.47	28.48	14.48	25.01	13.28	22.72	60.21	1.90	1.83
Heat	70.42	51.19	112.40	30.15	65.71	23.32	50.55	26.44	28.00	2.25	2.25	2.84
kg/p.p	9.97	5.21	10.74	3.38	6.82	2.74	5.47	1.95	3.67	4.52	0.30	0.34

Fig. 3. SO_2-equivalent emissions of the district energy production scenarios.

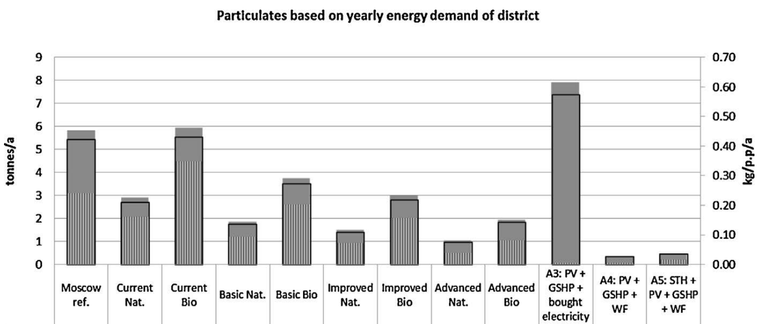
gas CHP plant and for an alternative biogas CHP plant. The emission from all the scenarios are pictured in Figs. 2–5.

4.2.2. Emissions for the Basic and Improved district scenarios

The annual emissions from natural gas CHP energy production and from biogas CHP energy production for both the Basic district scenarios and the Improved district scenarios were calculated based on the energy demands (Table 4) and corresponding distribution losses. See Figs. 2–5 for results.

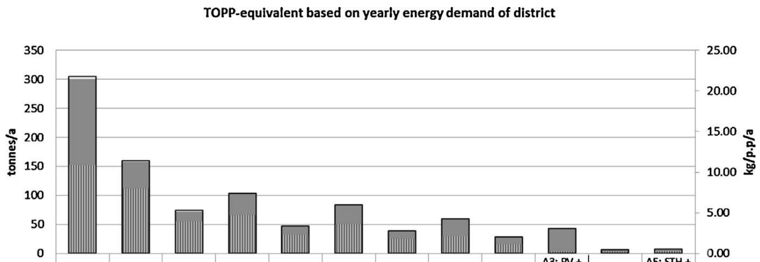
4.2.3. Emissions for the Advanced district scenarios

The advanced district scenario is a further improvement of the Improved district case in terms of energy demand (Table 4). Additionally, it contains several alternatives for energy generation from various combinations of renewable energy sources: natural gas CHP biogas CHP, building integrated solar photovoltaic (BIPV), solar collectors (STH), ground heat pumps, wind farms and electricity bought from the grid. The emissions from these can be found in Figs. 2–5.



	Moscow ref.	Current Nat.	Current Bio	Basic Nat.	Basic Bio	Improved Nat.	Improved Bio	Advanced Nat.	Advanced Bio	A3: PV + GSHP + bought electricity	A4: PV + GSHP + WF	A5: STH + PV + GSHP + WF
Elec	2.75	0.84	1.44	0.67	1.14	0.58	1.00	0.53	0.89	7.85	0.29	0.28
Heat	3.09	2.06	4.50	1.21	2.62	0.93	2.01	0.51	1.05	0.08	0.08	0.21
kg/p.p	0.42	0.21	0.43	0.14	0.27	0.11	0.22	0.08	0.14	0.57	0.03	0.03

Fig. 4. Particulates of the district energy production scenarios.



	Moscow ref.	Current Nat.	Current Bio	Basic Nat.	Basic Bio	Improved Nat.	Improved Bio	Advanced Nat.	Advanced Bio	A3: PV + GSHP + bought electricity	A4: PV + GSHP + WF	A5: STH + PV + GSHP + WF
Elec	148.23	45.68	17.64	36.19	14.04	31.80	12.38	29.07	11.65	38.52	2.70	2.60
Heat	152.77	112.39	55.31	66.05	32.89	51.01	25.61	29.47	16.12	3.98	3.98	4.50
kg/p.p	21.79	11.44	5.28	7.40	3.40	6.00	2.75	4.24	2.01	3.08	0.48	0.51

Fig. 5. TOPP-equivalent emissions of the district energy production scenarios.

For generating energy from solar radiation, the photovoltaic potential estimation utility Photovoltaic Geographical Information System (PVGIS) was used for estimating solar irradiation in Moscow [43]. According to this, the average yearly solar radiation on a horizontally inclined surface is 1.154 kWh/m^2 for an optimal surface in Moscow that has an inclination angle of 39° and south-orientation.

The annual electricity generation of the *solar photovoltaic* (*PV*) *system* was calculated as follows. Using CIS technology based solar panels (copper–indium–selenium) would give an annual generation of 1.060 kWh/kW$_p$ (temperature and reflectance losses included) which means that for every kW-peak power installed we get a 1.060 kWh of electricity in a year. Further losses (wiring, inverter, array mismatch and distribution) of the PV system were estimated to be a total 20% of the whole production [43,44]. The peak power per square metre ratio for the system was presumed to be 0.125 kW$_p$/m^2 [45]. The same number was multiplied with half of the roof surface of the buildings in the district for estimating the total annual electricity generation. Half of the roof area of the district was accounted for installing solar panels, and further that the roofs were horizontal which meant that solar panels could be oriented and inclined for optimal solar gain. The total annual production from the PV system is 1.655 MWh.

Solar collectors are estimated to cover for 30% of the energy for heating of domestic water which is a rough estimation based on the results of a pilot project in Helsinki in Finland [46]. The performance of *solar thermal heat* (*STH*) systems that were installed on multi-storey buildings was evaluated in the report. However, the saving potential of STH varies with solar radiation availability, system efficiency, outside temperature and utilization of heat collected which all complicates any accurate prediction. By accounting for solar thermal energy, the yearly demand for domestic water heating for an Advanced building will decrease from 32 kWh/m^2 to 23 kWh/m^2 resulting into a total heat demand of 61 kWh/m^2. This means that the total heating energy needed for the buildings in the Advanced district will become 20.011 MWh/a which is over 14% overall decrease when including solar thermal heating. One collector square metre produces annually 200–400 kWh for different types of systems and locations in Finland [47], and 450 kWh in Germany [48]. Results from PVGIS shows that the potential in Moscow is closer to that of Berlin than Helsinki. The value 400 kWh was used meaning that the total needed surface area needed for the solar collectors would be 8.011 m^2. The solar collectors might be roof-installed or placed on an open field and thereafter interconnected to form a large scale solar thermal heating system. The solar panels would occupy around 50% of the roof total roof area of the buildings and the collectors around 30% in case they were to be roof-top mounted.

The *ground source heat pumps* (*GSHP*) were decided to have a coefficient of performance (COP) value of 3, which means that each unit of electricity put in will generate three units of heat. Depending on how much heating is required there will be a certain amount of vertical boreholes needed for the ground source heating pumps. The amount of boreholes was calculated by calculating the total pipe length needed and dividing this with twice the maximum depth of a vertical borehole (200 m). Based on the demanded heating energy D_h, the length L of the pipe is calculated by

$$L = \frac{D_h}{G} \times 0.67 \quad [49] \tag{6}$$

The term G denotes the extractable amount of energy from ground which depends on the type of soil. In this study, the soil was assumed to be clay with the amount of extractable energy of 55 kWh/m^3. The value 0.67 in formula 1 comes from the ration of heat production for a GSHP with a COP value of 3. The pipe length can be twice the depth of a vertical borehole since it makes a loop in the end and return back to the surface again. This means that the total amount of vertical boreholes was calculated by dividing the total pipe-length for the whole district by 400.

Boreholes are to be placed 15 m from each other [49], which means that one borehole occupies at most 177 m^2 of ground surface. It has been considered that each II-18 building has a total floor area of 4.911 m^2 while the total floor area of the district is 327.581 m^2. The district scenarios in this study were considered to contain solely of II-18 buildings which means that the number of buildings in each scenario is 67. This number was later used for calculating how large area is required around each building for the installation of the boreholes.

In the *alternative 3*, 7.5% of the total electricity demand is generated by building integrated solar panels (BIPV), a total of 15 600 m^2 of panels, while the rest is bought from the grid. These would occupy half of the roof area as earlier mentioned. The heating demand is covered by ground source heat pumps (GSHPs) which in turn demand a considerable amount of electricity (included in the total demand). This alternative would require 556 boreholes and the ratio between the floor area and area needed for GSHP is 1/0.382. The energy demand and generation for this alternative are shown in Table 6 and the generated emissions in Table 7.

Alternative 4 is similar from the previous alternative except from the part that the additional electricity from the grid will be bought from wind farms (WF) located elsewhere. The energy demand and generation for this alternative are shown in Table 8 and the emissions in Table 9. The solar photovoltaic efficiency, and amount of boreholes and the area required for these are the same as in Alternative 3.

Table 6
Energy demand and generation for the advanced district alternative 3.

Annual energy demand (MWh/a)			Annual energy generation (MWh/a)		
Type	Heat	Electricity	Type	Heat	Electricity
Buildings	23 379	9943	BIPV		1655
Water and wastewater treatment	182	675	GSHP	23 561	
Street lights		242	Electricity from the grid		17 057
GSHP		7854			
Total	23 561	18 712	Total	23 561	18 712

Table 7
The emissions for the Advanced district scenario alternative 3 (A3: PV + GSHP + bought. . .).

	BIPV (kg/a)	GSHP (kg/a)	Grid (kg/a)	Waste incineration (kg/a)	Total (kg/a)	Total per person (kg/a/p.p)
Emissions into air						
SO_2-equivalent	291	293	59 378	2494	62 456	4.5
TOPP-equivalent	265	363	37 260	4613	42 500	3.1
Particulates	43	54	7794	38	7929	0.57
Greenhouse gases						
CO_2-equivalent	181 817	90 342	8 792 514	244 317	9 308 990	674

Table 8
Energy demand and generation for the advanced district alternative 4.

Annual energy demand (MWh/a)			Annual energy generation (MWh/a)		
Type	Heat	Electricity	Type	Heat	Electricity
Buildings	23 379	9943	BIPV		1655
Water and wastewater treatment	182	675	GSHP	23 561	
Street lights		242	WF		17 057
GSHP		7854			
Total	23 561	18 712	Total	23 561	18 712

In the *alternative 5*, solar collectors (STH) are producing 30% (8000 m^2) of the heating energy needed for the domestic hot water. The rest of the heat demand is covered by ground heat pumps (GSHP) which use also electricity for operation. Solar panels (PV) are producing the same amount of electricity as in alternatives 3 and 4 while the rest of the electricity demand is generated by wind farms (WF). The total amount of boreholes in this case is 458 which is less than for the precious cases since a share of the heating demand is covered by solar collectors. The ratio between the floor area and area needed for GSHP is thereby 1/0.314. The energy demand and generation for this alternative are shown in Table 10 and the emissions in Table 11.

4.2.4. Comparison of the different district cases

Generated emissions from the different scenarios are compared to each other and the value for the Moscow area (Moscow ref.) in Fig. 2 (CO_2-equivalent emissions), in Fig. 3 (SO_2-equivalent emissions), in Fig. 4 (particulates), and Fig. 5 (TOPP-equivalent emissions). The Moscow reference values are average emission values from energy production for the whole of Moscow. In order to

Table 9
The emissions for the Advanced district scenario alternative 4 (A4: PV + GSHP + WF).

	BIPV (kg/a)	GSHP (kg/a)	Wind farms (kg/a)	Waste incineration (kg/a)	Total (kg/a)	Total per person (kg/a/p.p)
Emissions into air						
SO_2-equivalent	291	293	1073	2494	4151	0.30
TOPP-equivalent	265	363	1436	4613	6677	0.48
Particulates	43	54	241	38	376	0.027
Greenhouse gases						
CO_2-equivalent	181 817	90 342	448 794	244 317	965 270	70

Table 10
Energy demand and generation for the advanced district alternative 5.

Annual energy demand (MWh/a)			Annual energy generation (MWh/a)		
Type	Heat	Electricity	Type	Heat	Electricity
Buildings	23 379	9943	BIPV		1655
Water and wastewater treatment	182	675	GSHP	20 356	
Street lights		242	STH	3205	
GSHP		6785	WF		15 989
Total	23 561	17 644	Total	23 561	17 644

Table 11
The emissions for the Advanced district scenario alternative 5 (A5: STH + PV + GSHP + WF).

	BIPV (kg/a)	GSHP (kg/a)	Wind farms (kg/a)	STH (kg/a)	Waste incineration (kg/a)	Total (kg/a)	Total per person (kg/a/p.p)
Emissions into air							
SO_2-equivalent	291	246	1001	636	2494	4667	0.34
TOPP-equivalent	265	304	1340	573	4613	7095	0.52
Particulates	43	45	224	132	38	482	0.035
Greenhouse gases							
CO_2-equivalent	181 817	75 745	418 716	118 005	244 317	1 038 600	75

be comparable, these have been converted to emissions per inhabitant and thereafter multiplied by the number of inhabitants of the case district.

Using biogas instead of natural gas would result in larger reduction of CO_2- and TOPP-equivalents but higher levels of SO_2-equivalents and particulates with all examined solutions. The reduction potential is especially high for CO_2-equivalents which can be reduced to below 10% for each scenario when switching to biogas. Buying electricity from the grid is not favourable and would cancel out the effect of using ground source heating pumps for reducing emissions in alternative 3.

By comparing the emission levels, alternative 4, involving PV, GSHP and WF, would generate lowest emissions. However alternative 5, involving STH, PV, GSHP and WF, was almost as good alternative because energy produced by a ground source heat pump is considered to result in fewer emissions than energy produced by solar collectors due to the fact that the electricity used by the heat pump was produced by wind energy. Storing excess heat from the solar collectors in the ground during hot seasons (summer) with help from GSHPs was not considered. Taking this into account could possibly have made alternative 5 the winning scenario.

5. Discussion and conclusions

5.1. Conclusions

At the district level, different improvement scenarios in terms of energy demand, energy production and emissions were analyzed. The district scenarios, named Current, Basic, Improved and Advanced, comprise the building renovation cases of the most typical apartment building type. The improvements accounted for in the district scenarios were the energy consumption of buildings, outdoor lighting, water purification, wastewater treatment, and transfer losses of district heating and electrical grid, and energy generation from renewable energy sources. Several studies [14,15,50–54] show the technical feasibility of renewable energy solutions in Russia.

Considerable energy savings could be achieved in a district through different modernization scenarios. Even with the basic district concept, the total annual electricity demand would reduce 24%, and the total annual heating demand 42% according to calculations. With the improved district concept, the corresponding reductions would be 33% and 55%. With the advanced district concept, potential reductions would be 34% for electricity demand and 72% for heating demand. It is clearly seen that savings in heat demand are easier to achieve than savings in electricity demand. One reason for this is that electricity demand is more connected to people's behaviours than the heat demand and is therefore harder to calculate and forecast. Almost all renovation activities also improve the quality of living, one such is the instalment of mechanical ventilation which often lower heat demand but increases electricity demand. It needs to be understood that a holistic approach to the analysis of the renovation activities is essential to draw the right conclusions.

The importance of analyzing the whole energy chain becomes evident when looking at cases where heat losses in the heat distribution network are very big and heat exchangers are lacking between networks and the buildings (as is the case in Russia). This leads to a situation where the reduced energy demand in a building does not lead to savings in the beginning of the energy chain but may instead even lead to overheating of the building. The energy saving investments might then be beneficial for the building occupants (if the investments also include control devices), but looking at the total benefits for the society such renovations would not bring such benefits as reducing air pollution, global warming, unnecessary investments into utility-level energy (and water) infrastructure etc.

The emission analyses show that the amount of each emission type produced might depend on different factors. As for CO_2-equivalents, changing fuels from natural to biogas would be an efficient choice of reduction. The same also goes for TOPP-equivalents, where it can be noted that changing fuel type would result in further reduction than implementing the next standard (e.g. Current to Basic) renovation. However, doing so would on the other hand also result in twice the amount of produced SO_2-equivalents and particulates. Concluding, producing energy from other renewable technologies than biogas, such as ground source heat pumps, solar panels, solar collectors or wind turbines, would be a better solution than switching to biogas when it comes to reduced SO_2 particulates emission levels compared to the current situation.

It can be concluded that there is no straight forward answer to which scenario is the best one, not even in terms of reduced emissions. Looking at CO_2 and TOPP emissions gives another conclusion than looking at SO_2 and particulates emissions. It needs to be clear what the objectives of the improvements are in order to make the right decisions in choosing the most efficient improvement scenario.

6. Discussion

There is no relevant scientific literature related to energy renovations of Russian residential districts, this study can be seen as a pioneer and forerunner in this sector. Even though the district examinations were made to one pilot area, their results can be generalized to other similar residential areas existing in Moscow as well as in other parts of Russia. The energy renovation of such districts requires often improvements to the whole energy chain while many building level renovations would only improve the energy-efficiency of the building itself. This means that if the same amount of energy is supplied to the building through uncontrollable district heating, the building energy consumption and emissions do not reduce.

The performed analysis highlights also the issue of a wide variety of stakeholders being involved in such renovation activities. City planning aspects need to be considered for example when considering the need for land use for bore holes or local heating plants. The roof top solar installations' inclination angles influence the solar energy production etc. Energy companies naturally have a big role in the infrastructural renovations of the energy infrastructure both considering production plants and the transmission lines and pipes. Ownership and management questions regarding ownership of energy plants, transmission networks and the buildings play a role in making the concepts realized.

Business models for carrying out such large scale renovation activities need to further investigated. The benefits of the different stakeholders, the incentives for realizing energy efficient district renovation concepts need to be elaborated. If energy is being subsidized the economic incentives might be lacking. If investments are paid by other stakeholders than the ones getting the benefits there is a barrier for executing the concepts. Public authorities need to have a clear role and strong will to make the concepts become reality.

Based on the result of this study it can be concluded that the renovation of a neighbourhood should not be restricted to the renewal of houses, but should be extended to the whole territory and whole energy chain in order to achieve the holistically best results. Furthermore, this study has shown (see Figs. 2–4) that the emissions to air correlate not only with energy efficiency, but are also highly dependent on the source of energy. For certain types of emissions (e.g. particulates) the effect of energy source is especially pronounced.

Acknowledgement

The authors wish to thank the Finnish ministry of foreign affairs for funding this research.

References

[1] S. Paiho, Å. Hedman, R. Abdurafikov, H. Hoang, M. Sepponen, I. Kouhia, M. Meinander, Energy saving potentials of Moscow apartment buildings in residential districts, Energy and Buildings 66 (2013) 706–713.
[2] R. Perelet, S. Pegov, M. Yulkin, Climate Change Russia Country Paper, UNDP – United Nations Development Programme, Human Development, Report 2007/2008, 2007/12, 2013, 30 p. http://origin-hdr.undp.org/en/reports/global/hdr2007-2008/papers/perelet_renat_pegov_yulkin.pdf (accessed 09.04.13).
[3] A. Korppoo, Russia and the post-2012 climate regime: foreign rather than environmental policy, the Finnish Institute of International Affairs, in: Briefing Paper 23, 2008, 8 p. http://www.upi-fiia.fi/assets/events/UPI_Briefing_Paper_23_2008.pdf (accessed 09.04.13).
[4] Y.-J. Zhang, Interpreting the dynamic nexus between energy consumption and economic growth: empirical evidence from Russia, Energy Policy 39 (2011) 2265–2272.
[5] P. Lahti, J. Nieminen, A. Nikkanen, J. Nummelin, K. Lylykangas, M. Vaattovaara, M. Kortteinen, R. Ratvio, S. Yousfi, Riihimäki Peltosaari – eco-efficient renewable of a neighbourhood, in: VTT Research Notes 2526, 2010, June, 107 p. + app. 13 p., http://www.vtt.fi/inf/pdf/tiedotteet/2010/T2526.pdf (accessed 17.06.13) (in Finnish).
[6] A. Korppoo, N. Korobova, Modernizing residential heating in Russia: end-use practices, legal developments, and future prospects, Energy Policy 42 (2012) 213–220.
[7] E. Zavadskas, S. Raslanas, A. Kaklauskas, The selection of effective retrofit scenarios for panel houses in urban neighborhoods based on expected energy savings and increase in market value: the Vilnius case, Energy and Buildings 40 (2008) 573–587.
[8] Å. Nystedt, M. Sepponen, Development of a concept for ecological city planning for St. Petersburg, Russia, in: World Renewable Energy Congress 2011 – Sweden, Linköping, Sweden, 8–11 May 2011, Sustainable Cities and Regions (SCR), 2011.
[9] S. Raslanas, J. Alchimovienė, N. Banaitienė, Residential areas with apartment houses: analysis of the condition of buildings, planning issues, retrofit strategies and scenarios, International Journal of Strategic Property Management 15 (2) (2011) 158–172, ISSN 1648-9179.
[10] United Nations, Country Profiles on the Housing Sector, Russian Federation, New York and Geneva, 2004, pp. 123, ISBN 92-1-116917-8, http://www.unece.org/fileadmin/DAM/hlm/documents/2005/ECE/hbp/ECE_HBP_131.e.pdf (accessed 10.01.13).
[11] International Finance Corporation (IFC) & European Bank for Reconstruction and Development, Financing Capital Repairs and Energy Efficiency Improvements in Russian Multi-family Apartment Buildings, Key Conclusions and Recommendations, 2012, pp. 32, http://www1.ifc.org/wps/wcm/connect/3f9bbb804cc01dfeadd0edf81ee631cc/PublicationRussiaRREP-Appartment Buildings-2012.pdf?MOD=AJPERES (accessed 24.06.13).
[12] Ministry of Energy of the Russian Federation, Energy strategy of Russia for the period up to 2030, 2010, 2013, pp. 172, ISBN 978-5-98420-054-7, http://www.energystrategy.ru/projects/docs/ES-2030_(Eng).pdf (accessed 21.06.13).
[13] M. Garbuzova, R. Madlener, Towards an efficient and low carbon economy post-2012: opportunities and barriers for foreign companies in the Russian energy market, Mitigation and Adaptation Strategies for Global Change 17 (2012) 387–413.
[14] M. Asif, T. Muneer, Energy supply, its demand and security issues for developed and emerging economies, Renewable and Sustainable Energy Reviews 11 (2007) 1388–1413.
[15] A.O. Pristupa, A.P.J. Mol, P. Oosterveer, Stagnating liquid biofuel developments in Russia: present status and future perspectives, Energy Policy 38 (2010) 3320–3328.
[16] Yu.A. Matrosov, I.N. Butovsky, R.K. Watson, Case studies of energy consumption in residential buildings in Russia's middle belt area, Energy and Buildings (1994) 231–241.
[17] M.W. Opitz, L.K. Norford, Yu.A. Matrosov, I.N. Butovsky, Energy consumption and conservation in the Russian apartment building stock, Energy and Buildings 25 (1997) 75–92.
[18] C.A. Balaras, K. Droutsa, E. Dascalaki, S. Kontoyiannidis, Heating energy consumption and resulting environmental impact of European apartment buildings, Energy and Buildings 37 (2005) 429–442.
[19] I.Y. Choi, S.H. Cho, J.T. Kim, Energy consumption characteristics of high-rise apartment buildings according to building shape and mixed-use development, Energy and Buildings 46 (2012) 123–131.
[20] R. Kyrö, J. Heinonen, A. Säynäjoki, S. Junnila, Occupants have little influence on the overall energy consumption in district heated apartment buildings, Energy and Buildings 43 (2011) 3484–3490.
[21] M.J. Kim, M. Eun, J.T. Kim, Energy use of households in apartment complexes with different service life, Energy and Buildings 66 (2013) 591–598.
[22] H. Tommerup, S. Svendsen, Energy savings in Danish residential building stock, Energy and Buildings 38 (2006) 618–626.
[23] J. Ouyang, J. Ge, K. Hokao, Economic analysis of energy-saving renovation measures for urban existing residential buildings in China based on thermal simulation and site investigation, Energy Policy 37 (2009) 140–149.
[24] T. Siller, M. Kost, D. Imboden, Long-term energy savings and greenhouse gas emission reductions in the Swiss residential sector, Energy Policy 35 (2007) 529–539.
[25] J. Ouyang, J. Ge, T. Shen, K. Hokao, J. Gao, The reduction potential of energy consumption, CO_2 emissions and cost of existing urban residential buildings in Hangzhou City, China, Journal of Asian Architecture and Building Engineering 7 (1) (2008) 139–146, ISSN 1346-7581.
[26] City of Moscow, The Housing programme of the City of Moscow for the period 2012–2016, Government of Moscow, Department for capital repairs, 2011, http://www.moskr.ru/dkr/ru/normative_base/n_138/o_50309 (accessed 17.06.13) (in Russian).
[27] S. Paiho, R. Abdurafikov, Å. Hedman, H. Hoang, I. Kouhia, M. Meinander, M. Sepponen, Energy-Efficient Renovation of Moscow Apartment Buildings and Residential Districts, VTT Technology 82, VTT, Espoo, 2013, 114 p. + app. 5 p., ISBN 978-951-38-7921-1 http://www.vtt.fi/inf/pdf/technology/2013/T82.pdf (accessed 28.03.13).
[28] I.I. Bobrovitskiy, N.V. Shilkin, Hybrid ventilation in multistory apartment buildings, ABOK Journal 3 (2010), http://www.abok.ru/for_spec/articles.php?nid=4573 (accessed 17.06.13) (in Russian).
[29] G. Keikkala, A. Kask, J. Dahl, V. Malyshev, V. Kotomkin, Estimation of the potential for reduced greenhouse gas emission in North-East Russia: a comparison of energy use in mining, mineral processing and residential heating in Kiruna and Kirovsk-Apatity, Energy Policy 35 (2007) 1452–1463.
[30] The International CHP/DHC Collaborative, CHP/DH Country Profile: Russia, 2009, pp. 12, http://dbdh.dk/images/uploads/pdf-abroad/IEA_Russia_16pp_A4_web.pdf (accessed 05.02.13).
[31] U.R. Fritsche, Kl. Schmidt, Global Emission Model of Integrated Systems (GEMIS 4.5) Manual, Ökö-Institut (Institute for Applied Energy), 2008, http://www.oeko.de/service/gemis/en (accessed 10.01.12).
[32] Global Emission Model for Integrated Systems (GEMIS). [A life-cycle analysis program and database.] http://www.gemis.de (accessed 05.06.12).
[33] United States Environmental Protection Agency (EPA), Particulate Matter (PM), 2012, http://www.epa.gov/airquality/particlepollution/ (accessed 11.06.12).
[34] IEA, Electricity/Heat in Russian Federation in 2008, International Energy Agency. http://www.iea.org/stats (accessed 26.09.11).
[35] T. Tukiainen, Greenhouse Gas Emissions of Finnish Water and Wastewater Utilities (Master's thesis), Helsinki University of Technology, Faculty of Engineering and Architecture, 2009, pp. 150, http://civil.aalto.fi/fi/tutkimus/vesi/opinnaytteet/tukiainen2009.pdf (accessed 14.01.13) (in Finnish).
[36] M. Radocha, B. Baumgartner, Energy Efficiency in Streetlighting and Transport Infrastructure, Reference Material for Competence, 2006, http://www.transportlearning.net/docs/Competence_reference%20material_urbandesign_en.pdf (accessed 30.10.09).
[37] B. Neenan, R.C. Hemphill, Societal benefits of smart metering investments, Electricity Journal 21 (October (8)) (2008) 32–45, 1040–6190.
[38] S. Paiho, M. Sepponen, R. Abdurafikov, Å. Nystedt, I. Kouhia, M. Meinander, H. Hoang, Feasibility on upgrading Moscow apartment buildings for energy

efficiency, in: 7th International Cold Climate HVAC Conference, Calgary, Alberta, Canada, 12–14 November, 2012, pp. 126–134, http://www.vtt.fi/inf/julkaisut/muut/2012/Feasibility_on_upgrading_Moscow.pdf (accessed 20.02.13).
[39] Echelon, Monitored Outdoor Lighting: Market, Challenges, Solutions and Next steps, 2007, pp. 19, http://www.echelon.com/support/documentation/papers/EchelonCorporation_StreetlightWhitepaper.pdf (accessed 30.10.09).
[40] M. Sepponen, Technologies and solutions for ecocity' energy supply (Master' thesis), Aalto University, Espoo, Finland, 2010, pp. 116.
[41] City of Moscow, The City programme energy conservation in construction in the City of Moscow during 2010–2014 and until 2020, Decree of Moscow government from June 9, 2009, N536 (version from 12.10.10), 2011, http://base.consultant.ru/cons/cgi/online.cgi?req=doc;base=MLAW;n=120043 (accessed 14.08.11) (in Russian).
[42] Moscow heat supply scheme, The scheme of heat supply of the City of Moscow for the period until 2020, Annex to the decree of government of Moscow N1508 from December 29, 2009, Available: http://base.consultant.ru (in Russian).
[43] European Commission, Joint Research centre, Institute of Energy and Transport, Photovoltaic Geographical Information System (PVGIS), 2012, http://re.jrc.ec.europa.eu (accessed 03.03.12).
[44] A. Gregg, T. Parker, R. Swenson, Real world examination of PV system design and performance, in: Conference Record of the Thirty-first IEEE Photovoltaic Specialists Conference, 3–7 January, United Solar Ovonic LLC, Michingan, 2005, pp. 1587–1592, http://www.electroroof.com/analysis/PVSC2005.pdf (accessed 15.05.13).
[45] European Photovoltaic Industry Association (EPIA), Solar Generation 6, Solar Photovoltaic Electricity Empowering the World, 2011, pp. 98, available at: http://www.epia.org
[46] Solpros, Ekoviikin EU-aurinkolämpöjärjestelmien jatkoseuranta, Loppuraportti, 2004, http://www.viikinuusiutuvaenergia.net/Ekov_Solpros_loppur_2004.pdf (accessed 11.10.11) (in Finnish).
[47] Motiva, Auringosta lämpöä ja sähköä, 2012, http://www.motiva.fi/files/6137/Auringosta_lampoa_ja_sahkoa2012.pdf (accessed 19.05.12) (in Finnish).
[48] L. Bosselaar, Calculating the contribution of solar thermal towards the world energy supply. We should harmonize the methodology, 2011, http://www.iea-shc.org/Data/Sites/1/documents/statistics/2-Bosselaar-THerra_Webinar.pdf (accessed 15.05.13).
[49] Suomen Lämpöpumppuyhdistys (SULPU), Lämpöpumppujärjestelmän suunnittelu, 2012, http://www.sulpu.fi/ (accessed 05.06.12).
[50] E. Martinot, Energy efficiency and renewable energy in Russia, transaction barriers, market intermediation, and capacity building, Energy Policy 26 (11) (1998) 905–915.
[51] OECD/IEA, Renewables in Russia, From Opportunity to Reality, 2003, pp. 116, http://www.iea.org/publications/freepublications/publication/RenewRus_2003.pdf (accessed 25.10.13).
[52] E. Douraeva, Opportunities for Renewable Energy in Russia, IEA, 2003, pp. 23, http://www.geni.org/globalenergy/library/energytrends/currentusage/renewable/wind/global-wind-resources/russia/renewablerussia.pdf (accessed 25.10.13).
[53] K.O. Povarov, V.B. Svalova, Geothermal Development in Russia: Country Update Report 2005–2009, in: Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25–29 April, 2010, http://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/0145.pdf (accessed 25.10.13).
[54] World Energy Council, 2007 Survey of Energy Resources, 2007, pp. 586, ISBN 0 946121 26 5, http://www.worldenergy.org/documents/ser2007_final_online_version_1.pdf (accessed 25.10.13).

Appendix C: Paper III: Energy efficiency rating of districts

Hedman Åsa, **Sepponen Mari**, Virtanen Mikko. Energy Policy, Vol. 65, pages 408–418.
doi:10.1016/j.enpol.2013.10.022

Energy Policy 65 (2014) 408–418

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Energy efficiency rating of districts, case Finland

Åsa Hedman *, Mari Sepponen, Mikko Virtanen

VTT Technical Research Centre of Finland, PO Box 1000, Espoo 02044 VTT, Finland

HIGHLIGHTS

- We have created a tool for assessing energy efficiency of detailed city plans.
- The energy source is the most important factor for efficiency of districts in Finland.
- Five case districts in Finland were analyzed.
- In this paper one residential district has in-depth sensitivity analyses done.

ARTICLE INFO

Article history:
Received 10 May 2013
Received in revised form
8 October 2013
Accepted 9 October 2013
Available online 29 October 2013

Keywords:
Renewable energy
Energy efficiency
City planning

ABSTRACT

There is an increasing political pressure on the city planning to create more energy efficient city plans. Not only do the city plans have to enable and promote energy efficient solutions, but it also needs to be clearly assessed how energy efficient the plans are. City planners often have no or poor know how about energy efficiency and building technologies which makes it difficult for them to answer to this need without new guidelines and tools. An easy to use tool for the assessment of the energy efficiency of detailed city plans was developed. The aim of the tool is for city planners to easily be able to assess the energy efficiency of the proposed detailed city plan and to be able to compare the impacts of changes in the plan. The tool is designed to be used with no in-depth knowledge about energy or building technology. With a wide use of the tool many missed opportunities for improving energy efficiency can be avoided. It will provide better opportunities for sustainable solutions leading to less harmful environmental impact and reduced emissions.

1. Introduction

The buildings sector has been recognized as a key sector of the economy in improving sustainability. The United Nations panel on climate change IPCC has estimated that the greatest greenhouse gas reduction potentials are available in buildings (IPCC, 2007). Concerning Finland, it has been estimated that a few percent higher investment in energy efficient construction and renovation can decrease total primary energy consumption of the country 4–5% by 2020 and 5–7% by 2050 (Tuominen et al., 2013).

Various environmental assessment tools have been developed for the building sector to improve sustainability and support decision making during the past few decades. Recently the focus of assessing energy efficiency and sustainability of built environment has expanded from single building level into neighbourhoods, district and even city level assessments (Haapio, 2012). There are already lots of different assessment tools for evaluating energy efficiency and sustainability, such as internationally well known LEED for Neighbourhood Development (LEED, 2011), BREEAM Communities (BREEAM, 2012) as well as CASBEE for Urban Development (CASBEE, 2007) and CASBEE for Cities (CASBEE, 2011). In addition, national assessment tools and frameworks for sustainable built environment are developed in specific projects in Finland. Lahti et al. (2010) developed a tool for evaluating eco efficiency of areas in the city of Helsinki.

Energy efficiency is one of the key targets for city planning, but at least among Finnish city planners, there is a lack of tools for evaluating the energy efficiency of districts. Especially support is needed when estimating the effects of different decisions and actions within a district. Feedback from city planners has shown that the existing tools are rather complicated to use and take too much time. A need for an easy and fast tool was expressed in the feedback. To fulfil this need, a tool for rating energy efficiency of Finnish districts was developed in Ekotaajama project between 2010 and 2012.

The target was to provide a quick and easy-to-use tool for evaluating energy efficiency of districts for city planners, focusing on aspects that can be influenced on a detailed city planning level. Energy efficiency rating is based on primary energy use, in order to take into account both the energy demand and the energy source.

* Corresponding author. Tel.: +358 40 5703798; fax: +358 20 7227001.
E-mail address: Asa.Hedman@vtt.fi (Å. Hedman).

0301-4215/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2013.10.022

It is possible to evaluate different areas, for example with centralised energy production systems, such as district heating, but also distributed energy production and separate energy production systems of buildings. Energy demand is being assessed mainly through the energy classification rating system taking the heating and electricity demand of buildings into account.

The decision to use primary energy as the indicator was done because of many reasons. The tool was to indicate energy efficiency, not low emissions. The use of primary energy supports the energy efficiency rating taking the whole energy chain into account. If emissions were to be used, it should be assessed which emissions to take into account and with what weighting factor. The common way to use only CO_2 eqv as indicator was dismissed because of many other emissions also having an important role. One example is particle emissions. In rural areas small scaled wood heating is common and can create lots of particle emissions which can have negative impacts on the local air quality. The tool was based on the energy classification rating systems which are based on primary energy demand; this was another reason for choosing primary energy and using the same primary energy conversion factors as in the energy classification rating system. The energy classification rating was in turn chosen because it enables city planners to easily evaluate the energy demand of the buildings without having building physics knowhow.

1.1. Finnish city planning processes

To better understand the use of the tool, a short description of the city planning process in Finland is given below.

The Land use- and Construction Law (LCL), that contains rules for both land use planning and instructions for constructing, was founded for the purpose of creating a healthy, safe and comfortable living environment where the needs of different population groups are taken into account. The purpose of the law is to:

- organize land use and constructing objectives to provide for good living environment,
- promote development in terms of ecological-, economical-, social- and cultural sustainability, and
- secure the possibility of individuals to take part in preparation of matters, quality of planning and interactivity, versatility of expertise and open publicity (Ministry of the Environment, 2012b).

Fig. 1 illustrates the hierarchy chain of urban planning in Finland. The Finnish Ministry of the Environment elaborates the Nationwide Objectives for Land Use (NOLU) based on the Land use- and Construction Law, international agreements and EU directives. The NOLU is for balancing the development of regions and therefore also dictating all of urban planning in the country. It contains strategic decisions on higher level such as those concerning nationwide road- or rail networks and harbours. Based on the NOLU regional councils prepare their regional plans which are to be approved by the Ministry of the Environment (FINLEX, 1999).

Each regional council prepares a land use plan for their own region which usually involves several municipalities. The regional plans in turn serve as a frame for urban planning in the municipalities. Urban planning on a municipal level is about bringing forth a master plan, a town- or detailed plan and in some municipalities also a shore plan.

The master plan is made to direct the development and land use for the municipality as a whole, while a detailed plan is more specific and concerns certain areas of the municipality. The master plan forms in that sense a bigger picture that detail plans must fit into. The shore plan on the other hand dictates the use of shoreland (often for vacation settlement) (FINLEX, 1999).

An important issue is that all municipalities do not have equal resources allocated to urban planning. Larger municipalities or cities have in general more resources than smaller municipalities, usually

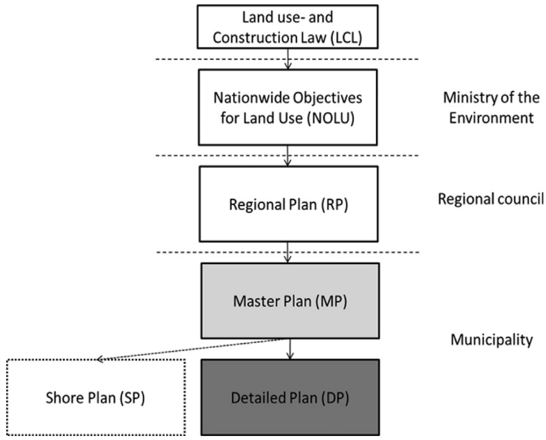


Fig. 1. The hierarchy chain of urban planning in Finland (FINLEX, 1999).

they have an own city- or urban planning department for developing both the master- and detailed plans. Urban planning departments mainly consist of architects and might often include land surveyors as well. Smaller municipalities may not have a department for urban planning and might therefore outsource some of the tasks to companies or consultants. Also, the responsibility of urban planning belongs to the head of urban planning department in larger municipalities, while in smaller municipalities it might be appointed as one of the tasks of a head engineer or technical manager. This further underlines the unequal prerequisites for urban planning between municipalities in Finland (Löytönen, 2011; Simons, 2011; Tommila, 2011).

The master plan is as earlier mentioned a general plan for directing the societal structure and land use of a municipality in its entirety. Existing social structures, economic- and ecological sustainability and natural values are to be paid attention to when a master plan is being developed. It also has to secure the inhabitants accessibility to social infrastructure and services such as water supply and sewage, energy- and waste management and roads.

A master plan could also be made for only a part of a municipality (partial-master plan) or jointly made by several municipalities (jointly drafted plan) (Ministry of the Environment, 2012b). The objectives and restrictions of a master plan are to be considered for the preparing of detailed plans. The detailed plan in turn defines the land use and construction of certain areas by taking into account local circumstances, city and scenery picture, and good construction methods (FINLEX, 1999).

A detailed plan includes a map where borders are declared for the planned areas. The map also contains information about what purposes different areas are going to be used for, the level of construction and principles regarding the localization and size of the building and also the method of construction when needed. Both the master and detailed plan are approved by the municipal council. According to the land-use and construction law, those people who are affected by the plans are also given the right to influence them (FINLEX, 1999).

Once a detailed plan is approved, it is the task of the building inspector to follow up on its implementation. The building inspector is responsible for ensuring that all construction is following plans and regulations, and that the built environment is safe and sustainable. They also grant building rights, offer counselling when needed, and decide in the end when a building can be brought into service (Ministry of the Environment, 2012b).

In the development of this energy efficiency rating tool, detailed city planning areas are considered as districts. One detailed city plan being one district. In the development project, Ekotaajama, five districts were analysed. The districts were small with a resident number varying between 85 and 180. The considered districts were all in rural areas in the Jyväskylä region and consisted mainly of residential one family houses. Two case areas also included also industrial buildings. However, the developed tool can be used for larger districts as well, and it can also include high rise buildings and other than residential buildings. The analysed cases are representing a very common residential district type in rural Finland. In this article a brief comparison of the different case districts are presented and one case district has been chosen for more in-depth sensitivity analysis.

2. Methodology for developing the energy efficiency rating tool for districts

The aim was to develop an energy efficiency rating tool for districts. The main target group of the tool users were city planning professionals. They may not be familiar with construction and energy production technologies. This fact was taken into account in the tool development. In practise, the tool had to be easy and quick to use. The rating tool is spreadsheet based, and is freely available in the internet (Jyväskylä Innovation, 2012). The input section of the tool is presented in Fig. 2.

An example of the results provided by the district energy rating tool is presented in Fig. 3. The format of the rating resembles the energy rating of buildings used in Finland.

Energy efficiency rating is based on primary energy consumption, in order to take into account both energy demand and used energy source. The tool is designed to compare different solutions within one district; therefore results comparing different districts are not comparable with each other. In order to get a good understanding about the expectations for the tool discussions were held with city planners from the five case cities in the Ekotaajama project. Additional to these interviews the results from a questionnaire that was done for city planners in another project, Ensio, was used.

District level energy classification

Surface area of the district	0.06	km^2
Total floor area of buildings	5350	m^2
Number of residents	156	
Number of apartments	39	
Area density	0.089	(Ratio of total floor area and districts' surface area)

1. Buildings

					Electrical sauna	Building sauna
Detached buildings, Energy Efficiency class		under 110 kWh/m2	B (151-170)	under 110 kWh/m2	☐	
Share of total floor area %	100 %	100 %	0 %	0 %		
District heat ☐		Renewable				
Building-specific energy production		Renewable	Renewable	Heat pump		
Row houses, Energy Efficiency class		G (over 280)	C (121-140)	C (121-140)	☐	
Share of total floor area %	0 %	100 %	0 %	0 %		
District heat ☐		District heating				
Building-specific energy production		Renewable	Fossil	Fossil		
Apartment buildings, Energy Efficiency class		G (over 280)	F (231-280)	E (181-230)	☐	☐
Share of total floor area %	0 %	100 %	0 %	0 %		
District heat ☐		Heat pump				
Building-specific energy production		Electricity	Renewable	Renewable		
Industrial buildings, Energy Efficiency class*		160	160	160	kWh/m^2,a	
Share of total floor area %	0 %	100 %	0 %	0 %		
District heat ☐		Renewable				
Building-specific energy production		Renewable	Renewable	Renewable		
Services buildings, Energy Efficiency class		under 100 kWh/m2	G (over 440)	under 100 kWh/m2		
Share of total floor area %	0 %	100 %	0 %	0 %		
District heat ☐		Fossil				
Building-specific energy production		Renewable	Renewable	Fossil		
Office buildings, Energy Efficiency class		E (171-230)	F (231-320)	under 70 kWh/m2		
Share of total floor area %	0 %	100 %	0 %	0 %		
District heat ☐		Renewable				
Building-specific energy production		Renewable	Renewable	Fossil		

2. Electricity production in the district

From renewable energy sources	15 %	Share of electricity produced from RES

3. Transportation solutions

Centralized parking at district's edge	☐	
Public transport stops	☑	
Bicycle routes	☑	Designed to promote cycling: smooth and pleasant experience
Bike storage/parking places	☐	Secure and easy to use

4. Distances to everyday services

Grocery store	1	km
Health center/clinic	4	km
School	3	km
Daycare	1	km

5. Work places

Remote work stations	0	pcs
Workplaces within the district	0	pcs

Fig. 2. The input and results sections of the rating tool.

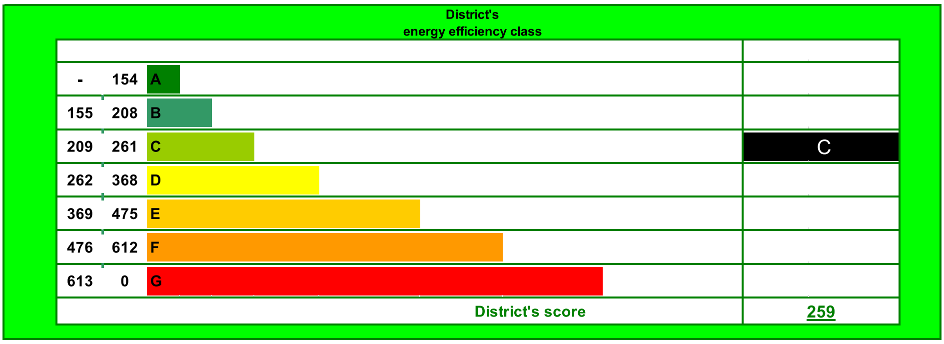


Fig. 3. The result diagram of the district energy rating tool.

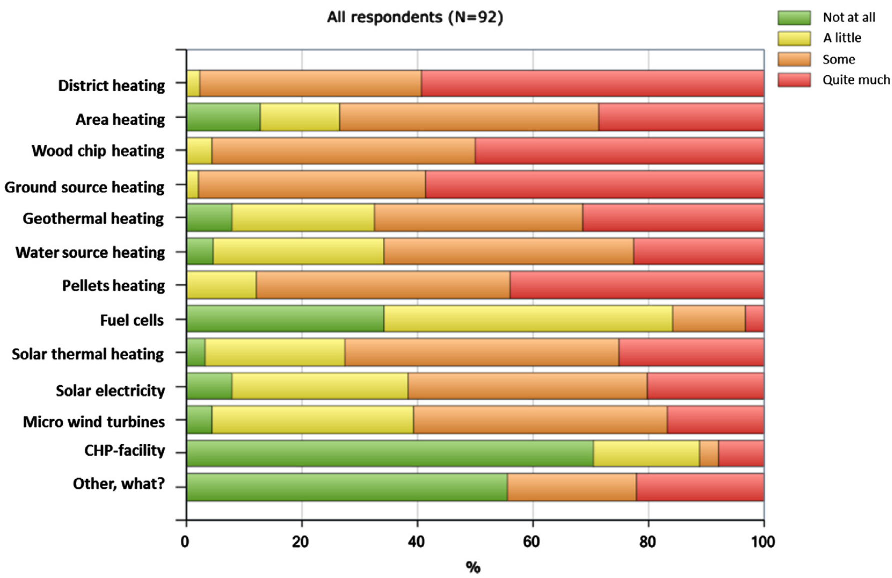


Fig. 4. Results of the questionnaires question "How familiar are the following energy systems?"

2.1. Questionnaire to city planners

A web-based questionnaire study was performed during January 2012 regarding the city planners and building inspectors views on energy related questions in the city planning process. The aim was to find out the level of knowhow and the need for supporting tools and guidelines. The questionnaire was sent to 100 city planners and 350 building inspectors covering all of Finland. There were 92 respondents, 58 from the building inspection and 32 from the city planning. There are 320 cities and communities in Finland (Kuntaliitto, 2013). The questionnaire was sent to over 300 cities and communities in Finland, answers received were 92. This represents about one third of the cities in Finland, which can be regarded as good hit rate and the results can be considered representative for the cities in general.

One of the results was that the term primary energy was rather unknown. Only 53% of the building inspectors and 63% of city planners answered that the term was familiar. This might be an issue to take into account when distributing the tool, since the calculations are based on the energy conversion factors and that needs to be clarified for the users.

The familiarity of different energy systems was also surveyed (see Fig. 4). District heating was very familiar solution, as could be expected since it is very commonly used in Finland. Surprising was that CHP (combined heat and power production) was unknown, 70% of the respondents didn't know at all what CHP is. This shows that the terminology used with energy experts and city planner experts is not always common. Most of the common renewable energy systems were rather well known. Solar energy systems received unexpectedly some "not known at all" answers.

The questionnaire also showed that it is felt as challenging to compare different energy systems and only a small portion of the respondents knew how they could improve the usage of renewable energy through the city planning.

Other challenges were the communication with decision makers, lack of resources and the information being to spread out and not enough processed. These are aspects that can be eased by the tool developed while it easily compares different alternatives and shows the energy efficiency rating of the district in a clear and understandable form.

2.2. Energy demand of buildings

City planners often have no building technology background. In order for them to be able to assess the energy demand of buildings, the energy labels assigned by energy certificates were used. The energy label rating system of each specific building type, such as detached building, has an individual scale of energy consumption for the labels from A to G. In Finland, current building regulations require that for each building the energy class (E-number) has to be calculated. Therefore it is an easy way to steer energy efficiency by demanding tighter E-numbers in the city plan or in the plot assignment stipulations. The plot assignment stipulations is an instrument used by the local authority to give detailed binding instructions about building and the use of the environment for private developers, in case the local authority as a landowner assigns (sells) the plot to a private developer for building, or the issue is agreed on in the land use agreement.

The Finnish E-number describing the total energy demand of the building was used as basis for the rating. It entails all energy use in building, including electricity, heating energy, and cooling energy demands. In addition, the energy source used is also taken into account in the E-number of the building by multiplying the energy demands with energy conversion factors of used energy sources. The number is a theoretical value, whereas the actual realised energy demand is naturally dependent on the inhabitants' behaviour and the sizes of the families living in the houses. It needs to be clearly stated that more specific energy calculations need to be done before making any investment decisions regarding the energy systems of a district (Ministry of Environment, 2009, 2012a).

For some building types there is no E-number system, (industrial buildings, churches etc.). For these kinds of buildings, a classification value was given in the tool to give estimates what is “normal energy demand level” and “low energy demand level”, which were based on the estimations provided by a Finnish construction element manufacturer (SP Elements, 2010).

Even though the tool does not go into details concerning electrical appliances in houses, saunas in buildings are still considered. This is because an electrical sauna has a significant effect on the electricity demand of a building, and especially on the maximum power peak load of the building. The power demand of a sauna oven is normally 6 kW. Using a sauna 3 times a week, one hour at a time, which is rather common in Finland, causes a yearly consumption of over 900 kW h per household. The tool has options for electrical or wooden heated sauna. In multi apartment buildings it can be chosen whether all the apartments have their own saunas or if the apartment has one common sauna. Saunas are culturally very important for the Finnish people. Even in new small city apartments small saunas are common. In one family houses and terraced houses close to 100% of the apartments have saunas. It is therefore very unlikely that we will see city plans in Finland forbidding saunas, at least in one family houses. There are, however, ways to increase the energy efficiency of saunas by decreasing the numbers and the usage of the individual saunas by offering a nice commonly used sauna in the district. Planning a nice and luxurious common wooden heated sauna in the area, for instance by a lake's shore, can be a better alternative than the own electrical small saunas in each building.

2.3. Analysis of energy production, distribution and source

To ensure the simple usage of the rating tool, the heating energy source is chosen based on the heat production systems, which were divided to renewable energy systems, heat pumps, fossil fuels and electricity. Similar classification of used energy sources and their energy conversion factors are used in the Finnish building regulations from 2012 (Ministry of Environment, 2012a). Used energy sources and their energy conversion factors are presented in Table 1. These energy conversion factors aim to represent the primary energy consumption of different energy sources in Finland. The Finnish electricity production mix is presented in Fig. 5. Additional to this 13.9 TW h (16.5% of the total demand) was imported in 2011 (Statistics Finland, 2011).

For each building type, the user of the tool has the possibility to select three different heat production systems. This is convenient especially when larger districts are analysed and buildings might not have uniform heating systems.

For ground heat pumps an estimation of yearly Coefficiency of Performance (COP) of 2.5 is used in the rating tool. This COP factor is set in the Finnish building regulations for the calculation of energy consumption of building, if better performance of heat pump cannot be proven (Ministry of Environment, 2007 D5). The electricity that the heat pump uses is converted to primary energy with the factor 1.7 according to Table 1. The heat distribution losses of district heating network are analysed on a rough level. This was done by analysing the statistic of all Finnish district heating network statistics provided by the Finnish Energy Industries (2009). The statistics have data about all Finnish district heating systems, including the length of the district heating networks, the total energy consumption in a certain district heating network and the heat distribution losses of the district heating networks (as relative to energy production). Analysis was done firstly by the calculating the key ratio of heat consumption density (MW h/m) by dividing in the total heat consumption per year (MW h) with the total length (m) of the network. This heat consumption density is

Table 1
Energy conversion factors in Finland (Ministry of Environment, 2012a).

	Energy conversion factor (used in calculating of Finnish E-number)
Electricity	1.7
District heating	0.7
District cooling	0.4
Fossil energy sources	1
Renewable energy sources (including wood and wood based and other biofuels)	0.5

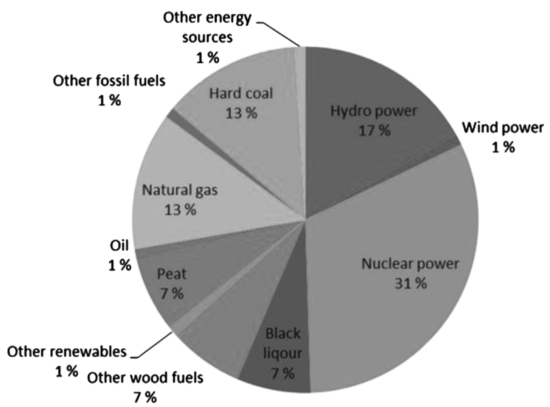


Fig. 5. The Finnish electricity production mix. Additional to this 13.9 TW h (16.5% of the total demand) was imported in 2011 (Satistics Finland, 2011).

mapped to the relative heat distribution losses of the distribution network, as presented in Fig. 6.

As a result of this analysis it seems that heat distribution losses from the distribution network tend to decrease when the density of the built area increases, as presented in Fig. 6. This is due to the increased energy consumption per distance of district heating network. This dependency was taken into account in the tool. The estimation of heat distribution losses was added to the total energy demand, if a district heating system was chosen as the used energy system in the tool. The calculated estimations of heat distribution losses are presented in Fig. 6.

The consumption density of majority of district heating networks is between 1 and 3 MW h/m. The variation in the relative losses presented in Fig. 6 on this range can be explained by the large number of different types of district heating networks as in such large array there is variation on the qualities and properties of the district heating networks. As Fig. 6 illustrates, the distribution losses may provide a substantial addition to the total energy consumption of the district. Thus, a correlation between the density of energy consumption (and thus, the density of the built area) in the district and the share of heat distribution losses from district heating from the energy consumption of the buildings was made. The share of losses relative to area density is presented in Table 2.

In addition to renewable heat sources, also renewable electricity production was taken into account. An input value in the tool is the percentage value of how much of the district's electricity need is produced in the district from renewable energy sources. The approximate electricity demand of the buildings can be derived from the E-number. A guideline is needed for city planners to assess how much of the electricity need of a district can be covered locally in the district with different installations of photovoltaic panels or wind turbines. For getting actually realistic and accurate energy production potentials, simulations would be needed. There are, however, no suitable simulation tools for the city planners for this purpose yet, and they might lack the knowledge to make such simulations. Moreover, the target of the rating tool is to give quickly and easily an estimate about the overall energy efficiency in the initial planning phase of a district. In order for the city planners to get the more precise production potential, they would need to order these simulations from consultants. This might in smaller cities be a cost that they might not be able to cover, and therefore a general estimation of the energy production potential is needed in order to get some indication of the production potential. There are several tools to assess the renewable energy generation potential. The tools can be found online, as browser based applications, but there are also tools for offline use. A tool to assess the photovoltaic electricity generation potential is developed by the Joint Research Centre (JRC) of the European Commission (JRC, 2012). A simple to use offline tool is the free version of IDA ESBO, which can be used to assess the potential of solar thermal energy generation, for example (ESBO, 2011). Finnish Wind Atlas is a simple tool to estimate wind power production in Finland (Wind Atlas, 2009). The planner could use these tools to estimate the influence of local measures to the electricity mix and the results obtained from these tools could also be used as an input for the energy rating tool.

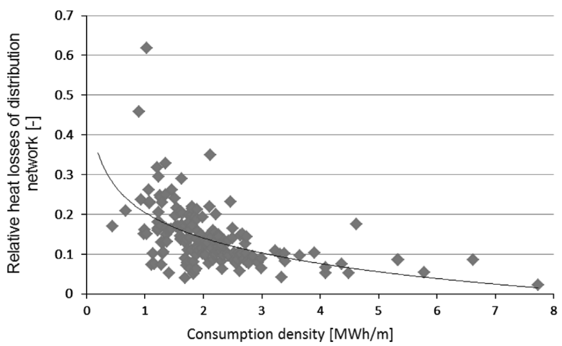


Fig. 6. The estimated ratio of the density of energy consumption and the relative heat distribution losses (which are relative to the total energy production) of district heating networks in Finnish cities (calculations based on data from Finnish Energy Industries (2009)).

Table 2
Heat distribution losses relative to the density of the area (e_a).

e_a (Floor area/total area)	(%)
under 0.1	25.0
0.1–0.3	15.6
0.3–0.5	9.8
0.5–1.0	5.9
1.0–2.0	2.8
Over 2.0	2.0

The realisation of local electricity production in the area cannot be forced directly through the detailed city plan, since it is not legally possible to force building owners to invest in photovoltaic panels or wind turbines. However, the utilisation of the renewable energy sources can be recommended in the plan. Furthermore, it can also be supported by the inspection of construction, which can take an active part with promoting renewable energy technologies. One possibility is also that the local energy utility invests in local renewable electricity production. A model worth considering could be that the energy utility rents the roof space of the residential buildings and owns the photovoltaic panels and handles everything regarding the electricity production. The business model could be further elaborated, for example the rent of the roof could be covered with a specific amount of electricity.

The city plan can enable renewable electricity production but cannot force it. Ways for enabling it is to direct houses optimally in regards to the solar energy production potential, i.e. roofs tilted towards the south with an angle of 40–45 degrees dependent on the latitude (Hoang, 2012). In addition, the shading of these roof surfaces from other buildings and trees should be minimised. Small scaled wind power can be promoted by mentioning in the plan that it is allowed to place small wind turbines on the roofs or on the lot. District level energy production systems, such as small scaled CHP plants or require a lot assigned for energy production and possibly needs storage spaces for fuel.

An obstacle for building specific renewable electricity generation is the lack of feed-in tariffs and immaturity of the Finnish transmission companies to receive and compensate for the fed in electricity. The bureaucracy is heavy and complicated and economic compensation is low (Marja-aho, 2011; Bionova, 2012).

2.4. Transport

Transport can in some districts account for up to 50% of the total energy demand of the district (Rajala et al., 2010). Therefore it is important to take into account solutions targeting to decrease the need of transportation, as well as increasing the energy efficiency of the transport, e.g. by affecting to the use of private cars. In this tool, energy use caused by transport was considered only in regards to transport performances that can be influenced by the detailed city plan, which means that the focus was on the transport inside of the district. Studied solutions in the detailed plans are: centralised parking in the outskirts of the district, bus stops, proper and separate ways for walking or bicycling and storage spaces for bicycles. The impact of local transport planning measures to the modal split of the district and was estimated to match the Finnish spatial setting. While the estimations were formed, studies on the effect of urban structure to the travel behaviour were used to assess the estimates (Naess, 2003).

The distance to daily services influence the transport demand significantly. In the tool the distance to the following services were inputs: grocery store, day care for small children, school and health care centre. An assumption was made that each service was visited five days a week per household except for the health care centre which was visited once a month per household. The relation between distance to services and the usage of private car was estimated on the basis of a study conducted by Jantunen et al. (2011) and is shown in Table 3. The energy consumption of the transportation to the services was calculated using the average energy consumption of cars in Finland, 0.68 kW h/km (LIPASTO, 2009).

The number of workplaces in the district also influences to the transport need. An average daily distance of 26 km to workplace per commuter was used to calculate the daily work transport of the area. This represents the Finnish average distance to workplace (Findikaattori, 2010). Each household was also assumed to have two commuters within them, which might be an optimistic assumption since many households have two cars, especially in the rural areas. The energy rating tool allows insertion of the estimated number of workplaces within the district as well as an estimation of teleworking possibilities with the district. The sum of these two is then reduced from the total number of commuting made from the district. It is to be noted that there are many possible awareness raising actions to take to reduce the use of private cars, these are however not actions that can be taken within the detailed city planning and are therefore left out of the scope in this study.

2.5. Calculation principles of the primary energy efficiency of the district

The energy efficiency rating was calculated by multiplying the energy consumption of the buildings and possible distribution losses of district heating system with the energy conversion factor of used energy sources and adding to it the primary energy demand of the traffic. That results the total primary energy demand of the district. The calculation procedure is presented in Eq. (1).

$$E-\text{number}=\frac{\Sigma_i(E_{cons,i}-E_{prod,i})f_i+E_{trans}}{A_{net}} \quad (1)$$

where, i=energy source, E_{cons}=energy consumption [kW h], E_{prod}=energy production [kW h], f=energy conversion factor, E_{trans}=energy consumption of transportation [kW h], A_{net}=net floor area of the building [m^2].

The rating of the district is made based on a comparison between the performance of best and worst scenarios. The classification scale is similar to the building energy certificate in Finland (Ministry of environment, 2012a,b). By putting input values describing the best available solution in terms of energy efficiency we define this as the A-class, the worst case scenarios values gives us the G class. The classification is then linearly divided between these.

Table 3
Share of trips made by private car relative to distance. (Jantunen et al., 2011).

	Share of trips made by car relative to distance		
	30%	75%	90%
Grocery store	Less than 0.9 km	0.9–1.5 km	Over 1.5 km
Day-care	Less than 0.9 km	0.9–1.5 km	Over 1.5 km
School	Less than 1.6 km	1.6–3 km	Over 3 km
Health care centre	Less than 0.9 km	0.9–1.5 km	Over 1.5 km

3. Results

The calculations of the five different cases used in the project, are shown in Table 4. The values inserted in the tool are representing most realistic values. It shall be noted that the energy efficiency class of the houses in Kannonkoski are poor (class C) due to the fact of them being log houses which are less energy efficient. Log houses have less strict energy efficiency demands in the building regulations due to technical difficulties in achieving high energy efficiency level. The district in Kannonkoski is a resort area where log houses are preferred due to cultural reasons. In the district in Petäjävesi heat pumps were not an option for heating source due to the fact that the district was an area with ground water. Often Finnish municipalities and regulators do not allow installing ground heat pumps to ground water areas due to the possible risks in contaminating the ground water when drilling the bore holes or in case of broken pipes.

Additionally the case area of Säynätsalo in the city of Jyväskylä is analysed more in-depth to analyse the impact of different choices on the overall energy efficiency.

The basic info about the district Säynätsalo and its detailed city plan is presented in Table 5. Basic information includes the floor area and number of residents of each of building types in the plan. The map of the Säynätsalo districts is presented in Fig. 7.

The case district only had residential buildings. In the designing phase of the detailed city plan, different plans were considered, such as containing only one family houses, or terraced houses, and one plan containing also a multi-story building.

As energy source it was most likely to have district heating in the area due to local circumstances. In specific Säynätsalo area district heating is produced mainly with bioenergy sources for the local wood residues.

In order to show the impact of different choices the following aspects of the city plan and its impact on the energy efficiency was analysed:

- Energy system (fossil, renewable, ground heat)
- Heat distribution (district heating network or building specific systems)
- Energy efficiency of buildings (different scenarios: energy classifications B, A, $<$A)
- Electrical sauna (yes/no)
- Local renewable electricity production (0–100% of household electricity demand)
- Transport:
  - Distance to daily services (0, 3 or 20 km)
  - Public transport and bicycle lanes taken into account in the plan (yes/no)
  - Work places in the area (0 or 50 work places)

In order to assess the impact of the listed aspects sensitivity analyses were performed were one variable at the time was changed, the rest being kept static.

3.1. Energy system

As building type one family houses were chosen. All buildings were of energy class A. No saunas were assumed in these calculations. Distance to daily services was 0 km, public transport and bicycle lanes were considered in the plan, and there were 50 working places in the district for all cases. Results of the energy system comparison calculations are seen in Table 6.

Rows 1 and 2 show that the primary energy factor raises significantly when the energy source is changed from renewable to fossil fuel. Comparing rows 3 and 4 shows that electric heating is consuming more primary energy than fossil fuel systems, which

Table 4
Comparison of cases and calculation of energy class with the tool.

Basic info	Säynätsalo	Kannonkoski	Jämsä	Petäjävesi	Toivakka
Districts total area [km^2]	0.06	0.0466	0,616	0.66	0.05
Total floor area [m^2]	5350	4004	39095	12650	2615
Numer of residents	156	156	150	200	85
Number of apartments	39	26	45	50	22
Density (floor area/total area)	0.9	0.09	0.06	0.02	0.05
Type and energ class of buildings					
One family houses [%, class]	80% A	100% C	70% A	100% A	100% A
Detached houses [%, class]	10% A				
High rise buildings [%, class]	10% A				
Industrial buildings [%, kW h/m^2,a]			30% 160		
Electrical saunas in individual buildings?	Yes	Yes	Yes	Yes	Yes
Heat transmission					
Local heat network	x		x		
No network, building specific heating systems		x		x	x
Energy source					
Electrical heating				50%	
Fossil fuel					
Renewable sources	100%		100%	50%	50%
Heat pumps		100%			50%
Renwable electricity	10%	30%	10%	10%	10%
Transport					
Centralised parking	No	Yes	No	No	No
Bus stops	Yes	Yes	Yes	No	Yes
Bicycle lanes	Yes	Yes	Yes	No	yes
Parking place for bicycles	No	No	No	No	No
Distance to service					
Grocery store	3 km	10 km	1 km	5 km	1 km
Health service	5 km	10 km	1 km	5 km	1 km
School	3 km	10 km	1 km	3 km	1 km
Day care	3 km	10 km	1 km	3 km	1 km
Working places					
Remote points	0	0	0	0	0
Working places	0	0	20	0	0
Result					
Primary energy	199	263	164	230	200
Energy class	**B**	**D**	**C**	**C**	**B**

Table 5
General information about Säynätsalo district.

Districts total area	0.06	km^2
Total floor area	5350	m^2
Numer of residents	156	
Number of apartments	39	
Density of the district	0.089	Floor area/total area

also can be easily seen from the primary energy factors in Table 1. The impact of renewable electricity production is seen on rows 5–9. Interesting is to see that the same total primary energy factor is achieved by having no renewable electricity production but heat the houses with renewable energy (row 9) and by having fossil fuel heating and 100% renewable electricity production (row 3). It is more cost effective to reach this level of primary energy demand by heating the houses with renewable energy sources than to produce all electricity with for instance solar panels. Comparing rows 2 and 3 shows the impact of transmission losses in the heat distribution system when having a local district heating system.

3.2. Energy efficiency of buildings

In the following analysis different aspects affecting the energy demand of the buildings have been changed. In all calculations there were building specific heating systems, distance to daily services were 0 km, public transport and bicycle lanes were considered in the plan, and there were 50 working places in the district for all cases. Results from the calculations are seen in Table 7.

As can be seen when comparing rows 1–4 in Table 7, the impact of the energy class is much higher when the heating system is electricity based. This is because of the higher primary energy factor of electricity compared to renewable sources. The impact of the electric sauna is seen on rows 5 and 6. It shall be highlighted that even though the yearly primary energy demand does not differ too much, the impact on the electricity peaks can be significant and affects the whole energy system when saunas are used widely and during same time periods, as is the case typically in Finland. Comparing rows 7 and 5 show the impact of building high rise buildings instead of one family houses. The difference is high since high rise buildings consume less heating energy per residential square meter.

3.3. Transport

In the following analysis different aspects affecting the transport demand have been changed. In all calculations buildings were one family houses, without saunas. In order to show the impact of solutions affecting transport demand, the building type was kept static in the different cases. One family houses were chosen since they are the most common type in rural districts in Finland. In reality the building types do influence the transport demand since availability of services are dependent on the residential density. This issue was however overseen since the services available were a variable input in this analysis.

All had building specific heating systems with renewable sources and 100% of the electricity demand was produced on site with renewable sources. Results from the calculations are seen in Table 8.

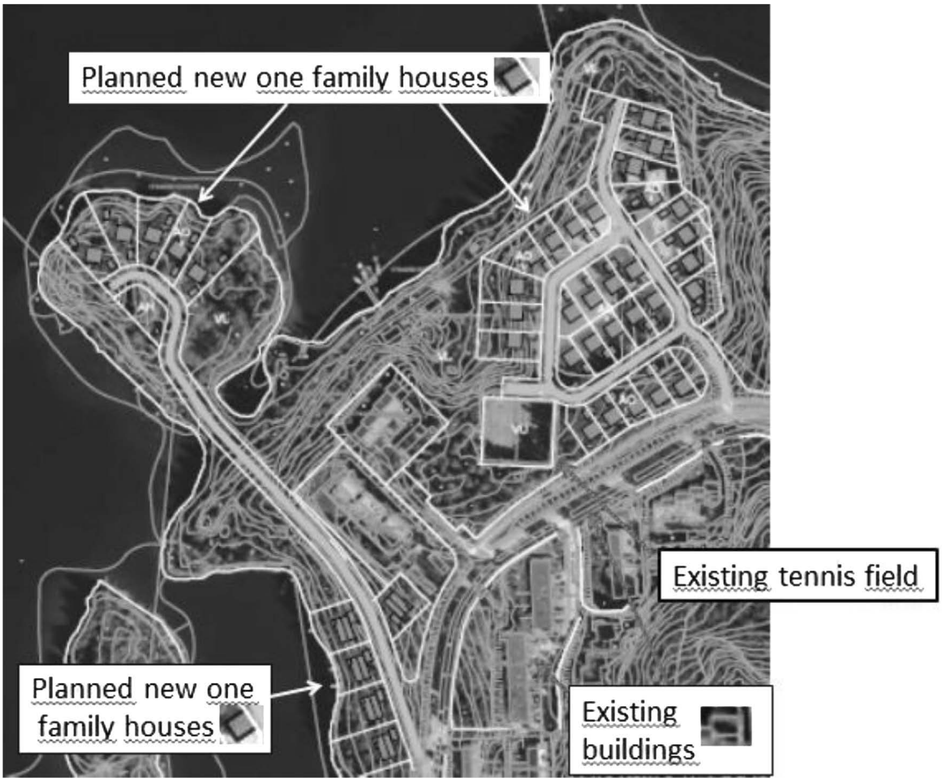


Fig. 7. Draft of the detailed plan of the Säynätsalo district (City of Jyväskylä, 2010).

Table 6
Energy system analysis.

	Local heat network	Heat source	Renewable electricity production (%)	Total primary energy need [kW h/m^2]	Total rating
1	Yes	Renewable	100	105	A
2	Yes	Fossil	100	168	A
3	No	Fossil	100	143	A
4	No	Electricity	100	213	C
5	No	Renewable	100	93	A
6	No	Renewable	75	105	A
7	No	Renewable	50	117	A
8	No	Renewable	25	129	A
9	No	Renewable	0	142	A

Comparing rows 1 and 2 in Table 8 shows the impact of taking public transportation and bicycle lanes into account in the plans. The difference is not very big. Rows 2 and 3 show the influence of reducing commuting to work. The case with 50 workplaces in the district would mean that almost all working people would have a job in the district. This is not realistic but is used as a best case scenario. Influence of this is rather high. The impact of the distance to daily services is seen when comparing rows 3, 4 and 5. Row 5 shows that when the distance grows up to 20 km it has a significant effect on the districts total energy efficiency. Rows 6 and 7 represent “best and worst case scenarios” in regards to transport solutions.

Table 7
Buildings energy demand analysis.

	Building type	Buildings energy class	Heat source	Sauna?	Total primary energy need	Total rating
1	One family	A	Renewable	No	142	A
2	One family	B	Renewable	No	152	A
3	One family	A	Electricity	No	262	D
4	One family	B	Electricity	No	296	D
5	One family	A	Renewable	No	142	A
6	One family	A	Renewable	Yes	153	A
7	High rise	A	Renewable	No	117	A

Table 8
Transport analysis.

	Distance to daily services	Public transport and bicycle lanes in the plan	Working places	Total primary energy need	Total rating
1	0	Yes	0	124	A
2	0	No	0	135	A
3	0	No	50	96	A
4	3 km	No	50	109	A
5	20 km	No	50	181	C
6	0	Yes	50	93	A
7	20 km	No	0	219	C

4. Discussion and conclusions

The tool developed is a simplified tool that gives practical help for city planners to assess the energy efficiency of detailed city plans in the design phase. The tool enables a fast and easy way to compare different alternatives of city plans and rank them in regards to energy efficiency. It needs to be highlighted though that the tool does not take into account the location of the district and can thus not be used to assess the overall energy efficiency of living in the district. Another tool or guidelines are needed to assess where to place residential districts in order to avoid transport demand and urban sprawl.

When analysing the impact of different choices made in the detailed city planning phase, it can be concluded that the choice of energy system has a significant impact on the overall energy efficiency. However, the importance of well insulated and airtight buildings shall also be highlighted. Heating systems can be changed in later stages of the buildings life cycle more easily than the energy efficiency of the house can be improved. A big part of the energy use in the district is at the end influenced by the actions of the people living there. Emphasise should be put on increasing people's awareness about their living habits and its impact on the energy efficiency. These are, however, aspects that are not very easily done through the city planning. Availability of daily services and public transportation are the obvious issues that can be influenced. Domestic electricity use is more difficult to influence.

A more precise calculation method for assessing the transmission losses dependences on the city plans is needed and is a topic for further research.

It needs to be noted that the tool is to be used for assessing different choices within a district and compare their effects on the districts energy efficiency. It is not suitable for comparing different districts with each other.

A limitation of the tool is that regarding transport, the tool only assesses decisions made within the area and its impact on the transport need, it does not take into account the transport need to and from the district. It therefore needs to be clearly stated when taking the tool into use that in the previous planning stage, where the placement of new residential districts is decided, other tools and methods need to be used in order to plan wisely and not plan districts that make the urban sprawl effect worse, leading to highly car dependent neighbourhoods.

A limitation of the tool is that it only assesses the energy efficiency from the technical point of view, not taking socio-economic aspects into account. The addition of these aspects is a topic for further research and development. Including socio-economic assessment of different solutions makes the tool more usable for decision making support.

The developed tool evaluates environmental sustainability of a district via analysing its primary energy demand. The tool guides towards decreasing the primary energy demand of the area, when targeting to get better classification from the tool. This primary energy demand evaluation includes energy demand of buildings and transportation as well as used energy system and source. Even though the tool itself does not estimate CO_2 emission from the area, it still contributes towards this goal. Firstly, if energy demand of buildings is decreased, it decreases similarly the emissions from energy production caused to cover the demand. Similarly emission reduction results the energy demand of transportation, it its energy efficiency can be improved or transport needs decreased. Furthermore, the primary energy analysis tool takes into account the used energy source via Finnish energy conversion factors (see Table 1), which are valued partly based on their environmental impacts. These energy conversion factors are more judgemental for electricity (with 1.7 factor), and support utilisation of renewable energy (0.4 factor) as well as district heating (0.7) and district cooling (0.4). Even though these relationships are not directly same than CO_2 emission rates, they do support targets to decrease CO_2 emissions.

The question of whether more tight regulations in city planning leads to a more sustainable built environment is a topic of discussion on many levels. With tools like the presented in this paper a tighter regulation could be steered towards more sustainable solutions. Today the city planners don't have the possibility to decide and rule about what energy source people choose for their houses or whether they take into use energy monitoring technologies. If they would have better opportunities to regulate what is being built and how people are living, tools help to lead to the environmental corner-stone of sustainability being improved. The social wellbeing corner stone would however probably decrease due to less possibilities for affecting choices related to peoples own houses and ways of living. The economic part is dependent on the solutions chosen. This contradiction could be overcome by developing a tool that would take into account all three corner stones of sustainability in the assessment of different solutions. That way the planners could regulate solutions that are overall sustainable.

Acknowledgements

The district's energy efficiency rating tool was developed in Finnish Ekotaajama project, which was funded by Sitra, Tekes and Finnish cities of Jyväskylä, Toivakka, Multia, Petäjävesi, Jämsä and Kannonkoski.

The questionnaire study was done within Ensio project funded by VTT.

References

Bionova Consulting, 2012. Selvitys sähkön pientuotannon nettolaskutuksesta. Työ- ja elinkoeinoministeriö, (referred 25.10.2012) Available: ⟨http://www.tem.fi/files/33435/Bionova-_selvitys_sahkon_pientuotannon_nettolaskutuksesta.pdf⟩.

BREEAM 2012: BREEAM Communities – Technical Manual. SD202 – 0.0.2012.BRE Global Ltd. Available: ⟨http://www.breeam.org/communitiesmanual/⟩.

CASBEE 2007: CASBEE for Urban Development—Technical Manula 2007 Edition. Institute for Building Environment and Energy Conservation (IBEC).

CASBEE 2011: CASBEE for Cities—Technical manual 2011 Edition. The Committee for the Development of an Environmental Performance Assessment Tools for Cities. Japan Sustainable Building Consortimu (JSBC).

City of Jyväskylä, 2010: Draft of a Detailed Plan of the Säynätsalo Area, Figure From the City Planning Department.

ESBO. 2011. IDA Early Stage Building Optimization. Available online: ⟨http://www.equaonline.com/esbo/index.html⟩. Referred to 20.9.2013.

Finnish Energy Industries 2009. District Heating Energy Statistics from 2009. Available (12.12.2012): ⟨http://energia.fi/tilastot-ja-julkaisut/kaukolampotilastot⟩ (in Finnish).

Findikaattori 2010. Availabale (1.2.2011): ⟨http://www.findikaattori.fi/fi/70⟩.

FINLEX. 132/1999 Maankäyttö- ja rakennuslaki. [Online article]. [Referred at in 28.1.2012]. Available at: ⟨http://www.finlex.fi⟩.

Haapio, Appu, 2012. Towards sustainable urban communities. Environ. Impact Assess. Rev. 32 (2012), 165–169.

Hoang, Ha. 2012. How Urban Planning Could Better Contribute to Opportunities for Utilizing Solar Energy in Finland. Masters's Thesis. Aalto University, School of Engineering. 100 pp.

IPCC 2007. Summary for Policymakers—Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Jantunen J. ,Penttinen M., Rämä P.,EBEN Summary. Eco-Efficient Bulit Environments —User Acceptance of Eco-efficient Solutions Related to Mobility. 17 s. 30.6.2011.

JRC. 2012. Interactive Access to Solar Resource and Photovoltaic Potential. Available online: http://re.jrc.ec.europa.eu/pvgis/. Referred to 20.9.2013.

Jyväskylä Innovation. 2012. Ekotaajma Project Results. (in Finnish). Available (7.12.2012): ⟨http://www.jklinnovation.fi/default/www/jyvaskyla_innovation_oy/osaamiskeskusohjelma/energiateknologia/projektit/⟩.

Kuntaliitto 2013. Association of Finnish Local and Regional Authorities. Available online: ⟨http://www.kunnat.net/fi/kunnat/toiminta/perustiedot/Sivut/default.aspx⟩ Refered to 17.9.2013.

Lahti P., Nieminen J., Nikkanen A., Puurunen E. Helsingin kaavoituksen ekotehokkuustyökalu (HEKO) (in Finnish). VTT; 2010. Available: ⟨http://www.hel.fi/static/public/hela/Kaupunkisuunnittelulautakunta/Suomi/Esitys/2010/Ksv_2010-11-11_Kslk_32_El/547EC356-9F25-4E0E-87E6-FD71878F5B6F/HEKO2-raportti_04112010_valmis.pdf⟩.

LEED. 2011. Homepage of LEED [web page] 〈http://www.usgbc.org/DisplayPage.aspx?CMSPageID=148〉 Accessed Nov 2012.
LIPASTO 2009. A Calculation System Covering Emissions and Energy Consumption of all Traffic Modes in Finland Has Been Completed in Technical Research Centre of Finland (VTT). Available (1.2.2013): 〈http://lipasto.vtt.fi/indexe.htm〉.
Löytönen, E., 2011. Head of the City Planning Department. City of Porvoo, City Planning. 06100 Porvoo, Rihkamatori B. Interview 7.12.2011.
Marja-aho Lauri, 2011: Uusiutuvan energian tuet EU maissa, selvitys uusiutuvan energian tukimalleista sähkön- ja lämmön tuotannossa EU-maissa. Aalto yliopisto. 84p. Available (25.10.2012): 〈http://energia.fi/sites/default/files/energiteollisuus_raportti_28_9_2011_2.pdf〉.
Ministry of Environment. 2007. D5 Calculation of Power and Energy Needs for Heating of Buildings. Guidelines 2007. Available at: 〈http://www.finlex.fi/data/normit/29520-D5-190607-suomi.pdf〉.
Ministry of Environment. 2009. Energiatodistusopas 2007, rakennuksen energiatodistus ja energiatehokkuusluvun määrittäminen 2.7.2009. Available: 〈http://www.ymparisto.fi/download.asp?contentid=105735&lan=fi〉 (in Finnish).
Ministry of Environment, 2012a. D3 Energy Management in Buildings Regulations and Guidelines 2012. Available at: 〈http://www.finlex.fi/data/normit/37188-D3-2012_Suomi.pdf〉 (in Finnish).
Ministry of the Environment. 2012b. Maankäyttö- ja rakennuslaki. [Online article]. [Referred at in 27.1.2012]. Available at: 〈http://www.ymparisto.fi〉.
Naess, 2003. Urban structures and travel behaviour. Experiences from empirical research in Norway and Denmark. Eur. J. Transp. Infrastruct. Res. 3 (2), 155–178. (2003).
Rajala, P., Hirvonen, H., Perttula, S., Lähde, E., Pulkka, P., Jarmala, L., Laukkanen, J., Patronen, J., Jokinen, M., Rintala, T., Rajakallio, K., Kauppinen, T. Energiatehokkuus kaavoituksessa. Publications of Sitra. ISBN:978-951-563-742-0 (URL: 〈http://www.sitra.fi〉).
Simons, B. Metering technician. Municipality of Maalax, Technical department. FIN-66101 Maalax, Malmgatan 5. Interview 10.12.2011.
SP Elements. 2010. Hallipeli—Hallin rakentamisen kustannusarvio. Available (1.2.2011) at: 〈http://www.hallipeli.fi〉.
Statistics Finland. 2011. Appendix fig. 1 Electricity Generation by Energy Sources 2011. Available online: 〈http://www.stat.fi/til/salatuo/2011/salatuo_2011_2012-10-16_kuv_001_en.html〉 (refered to 17.9.2013).
Tommila, T. Architect, Detailed Planning. City of Jyvaskyla, Urban Planning Department. 40101 Jyvaskyla, Hannikaisenkatu 17. Interview 9.12.2011.
Tuominen, P., Forsström, J., Honkatukia, J., 2013. Economic effects of energy efficiency improvements in the Finnish building stock. Energy Policy 52, 181–189.
Wind Atlas. 2009. Finnish Wind Atlas. Available online: 〈http://www.tuuliatlas.fi/fi/index.html〉. Referred to 20.9.2013.

Appendix D: Paper IV: Business concepts for districts’ Energy hub systems with maximised share of renewable

Sepponen Mari, Heimonen Ismo. Energy and Buildings, Vol. 124, pages 273–280.
http://dx.doi.org/10.1016/j.enbuild.2015.07.066

Energy and Buildings 124 (2016) 273–280

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Business concepts for districts' Energy hub systems with maximised share of renewable energy

Mari Sepponen*, Ismo Heimonen

VTT Technical Research Centre of Finland, P.O. Box 1000, FI-02044 VTT, Finland

ARTICLE INFO

Article history:
Received 26 March 2015
Received in revised form 13 July 2015
Accepted 28 July 2015
Available online 7 August 2015

Keywords:
Business concept
Business model
District energy systems
Renewable energy

ABSTRACT

This paper presents a set of new potential business concepts developed for districts' smart energy solutions with maximised utilisation of renewable energy (so called Energy hub systems). The concepts are targeted for different stakeholders with varying business ideas for optimal energy services and business. The concepts are presented in the form of a cookbook – a collection of business and service model recipes that describe the key idea and needed interactions between main stakeholders. Also costs and benefits of the business models are described, as well as key performance indicators for measuring the success for the stakeholders. The concepts are developed utilising Osterwalder's business canvas approach based on stakeholders' needs related to the energy demand and supply. The concepts are kept simple and focusing on one stakeholder at a time, thus improving significantly their clarity and enabling their further integration to energy analysis and simulation. These single business concept elements can be combined into broader and more specific business models, service offerings and business networks. Two specific example cases and one real life case area study are presented as examples. In addition, barriers for new Energy hub business and services are discussed.

1. Introduction

Currently lots of efforts are put on research and technical development related to improving energy efficiency, increasing the share of renewable energy, and improving of districts' energy systems. Most of the required technologies exist already, there are experiences about integrating them together, and they have been also piloted in several case areas. However, the wide-scale roll-out of more sustainable district level energy systems is yet to come. For this development, business models play a key role in the wide-scale implementation of new sustainable neighbourhood energy systems.

This paper presents the development process and a collection of business concepts developed for renewable energy based smart district energy systems, which are called in eHUB research project [1] as the Energy hub systems. According to the definition used in the project [1] "An Energy hub is a physical cross point, similar to an energy station, in which energy and information streams are coordinated, and where different forms of energy (heat, electricity, chemical, biological) are converted between each other or stored for later use". It is a mechanism for optimised energy and information supply exchange that integrates via various energy networks its members (households, renewable energy plants, offices, and businesses). These members can be both energy consumers and producers [1].

There are already some business models that could be potential for Energy hub systems, such as public private partnership models and its different variations. In addition, there are also some other interesting energy service related business concepts. Energy performance contracting (EPC) is a model, in which the service is defined in the level of energy performance and the client is buying the energy performance (e.g. for a building). Another interesting model is an energy service company (ESCO), which is a company delivering energy services. ESCO assumes the financial risk relative to energy projects and gets payment, e.g. according to the extent of realised energy savings. As an example, in an ESCO project the service provider optimises its customers' energy consumption through implementing energy efficient technologies and controls and by optimising the energy consumption, primarily with respect to heating and lighting [2].

2. Methodology

The overall methodology for developing business concepts for Energy hub systems consisted of following actions: a stakeholder

* Corresponding author.
E-mail addresses: mari.sepponen@vtt.fi (M. Sepponen), ismo.heimonen@vtt.fi (I. Heimonen).

http://dx.doi.org/10.1016/j.enbuild.2015.07.066
0378-7788/

analysis; development and analysis of business concepts; and an overview of the risks and barriers of energy business concepts are discussed in Section 5.

At first, an analysis of main stakeholder groups was done to understand the key players and their roles and needs in energy business (Section 3.1). Then a questionnaire was done to identify main stakeholders' needs related to energy services, focusing especially to end users (energy consumers) and energy service providers (Section 3.2).

The method for presenting business concepts was modified from the Osterwalder's business canvas approach [3] (Section 4.1). A preliminary list of possible concept level models was developed in a workshop. Then these business model ideas were further developed and analysed, resulting a cookbook: a collection of business concepts for Energy hub systems. All concepts were kept simple and focusing on one stakeholder at a time (Section 4), which simplified their further analysis. The analysis was done for all cases, of which two examples are presented in Sections 4.1 and 4.2.

2.1. Development of business concepts

This paper focuses on the development of business concepts, which are general level business ideas and elements. Business models are their next, more mature level for real life company specific operation models. Many typical European Commission (EC) funded projects state that they are studying and developing business models, although in reality they are usually working at the business concept level.

Among different research and coordination and support projects related to energy efficient neighbourhoods and buildings, different methods are used for developing business concept. Many EC funded projects, such as IDEAS [5] and Ambassador [6] define at first use cases, secondly define their relevant stakeholders and actors, and finally develop business scenarios and/or concepts for selected use cases. Another used development strategy is to build business concepts through executive workshops with the main stakeholders involved. Many other projects, such as EEPOS [7], are also describing business concepts and models via Osterwalder's business canvas [3]. As practical experience from these projects with business canvas, it is important to define data, energy, and monetary flows.

The common approach in analysing business and service concepts is the Osterwalder's approach [3] describing the product, customer interface, infrastructure management and financial aspects in nine different subtopics. In this work, the Osterwalder's model was simplified by choosing some elements of the model into the analysis. The structure of the analysis is presented in Table 1. All selected business concepts are described according to this structure. In addition, each concept is visualised by showing stakeholders and their main interactions related to the business concept.

2.2. Key performance indicators for measuring the performance

The performance of the business and services models is measured with key performance indicators (KPIs). Potential key performance indicators are presented in Table 2, in which KPIs are classified into three groups: environmental, economic and service level indicators. The KPI's will be selected by the stakeholders measuring the success of the model. As an example, energy consumer can measure the performance based on the total energy consumption and energy costs.

For each business concept or model, a suitable set of KPIs can be chosen based on the objectives and needs of the organisation at a given time. The metering of KPI's will give basis for evaluation of the success of business model concepts.

Table 1
Structure of the business concepts.

Elements	Description
Title	Describe in a few words the essence of the business model.
Business idea/objective	Describe in a few sentences the objective of the business model.
Offer/value proposition	Describe in a few sentences the service/product offered.
Customer	Who will use the service/product?
Seller/service provider	Who will offer the service/product?
Earnings/revenue model	Who pays, where does the money come from, and what needs to be bought? Who is the owner of this business?
KPIs	Main KPIs to measure the success of the concept. See Section 4.1.2.
Costs and benefits	What investments are needed? What are the costs and benefits?
References	Note, if the business model/idea is studied or applied somewhere else.

3. Stakeholder analysis of the Energy hub systems

3.1. Stakeholders' roles

The development of the business and service concepts requires the understanding of influencing stakeholders and their needs, goals and roles in energy business. A map of stakeholders is presented in Fig. 1. The main stakeholders are end users and service providers, who are running the practical actions in districts' energy business. The authorities and non-governmental organisations will give the regulation, rules, boundaries and public acceptance for the business. Main actors and their typical roles are described in Table 3. The basic needs of the main stakeholders are:

- End users: reduction of energy bill, reduction of energy consumption, improvement of energy efficiency, reliability and dependability.
- Energy network operators: balancing the network (achieving a calculable load).
- Energy retailers: reduction of imbalance (difference between predicted use and real use), and optimisation of energy trade.
- Project developers and investors: power peak shaving to limit maximum power and therefore reduce investment cost of the grid.
- Society and environment: reduction of CO_2 emissions, reduction of energy consumption, improvement of energy efficiency, maximising use of (local) renewable energy production.

3.2. Stakeholders' needs and attitudes towards Energy hub systems

The web questionnaire was carried out to find out the attitudes of stakeholders to smart energy [4]. The end users are interested to have green energy (produced by renewables, environmentally friendly, produced ecologically). The price of energy is important aspect and end users do not want to pay any extra or are willing to pay only small additional price of green energy, typically less than 10% extra price. The end users are interested in possibilities for own local production of energy and smart metering showing the consumption and costs of energy in own household. The users would likely use smart energy management service optimising energy consumptions and costs. The end users are interested in buying pools and demand side management pools. The service providers are willing to offer energy efficiency services (e.g. ESCO services), bundled energy services (e.g. heat/cool and electricity) and services minimising energy consumption and costs. The results

Table 2
Environmental, economic and service level key performance indicators.

Environmental KPIs	Finance and business KPIs	Service level agreement KPIs
(Average) primary energy consumption	Total purchased/sold energy	Delivery precision
Total energy (power, heating, cooling, fuels) generated	Profitability for the different stakeholders involved	Response time (for a service request)
Total renewable energy generated	Total turn-over (of energy trading i.e. purchased/sold energy and services)	Mean time between failure (time to repair)
Total energy stored	Total profitability	Reliability of energy provision
Total on-site produced renewable energy	Total energy costs	Security of energy provision
Energy saved due to conservation and efficiency improvements and changes to renewable energy production	Cash flow return on investments (e.g. net present value (NPV), Internal rate of return (IRR), and Return on investment (ROI))	
Total greenhouse gas (GHG) emissions	Total assets	
Other emissions, such as SO_2 equivalent, small particles, etc.	Sales per service	
GHG emissions saved (due to conservation and efficiency improvements and changes to renewable energy generation)	Profit per service	
	Total investments/capital expenditure	
	Total current liabilities (e.g. service contracts, leasing contract etc.)	
	Number of customers/service contracts	
	Customer satisfaction/reclamations	

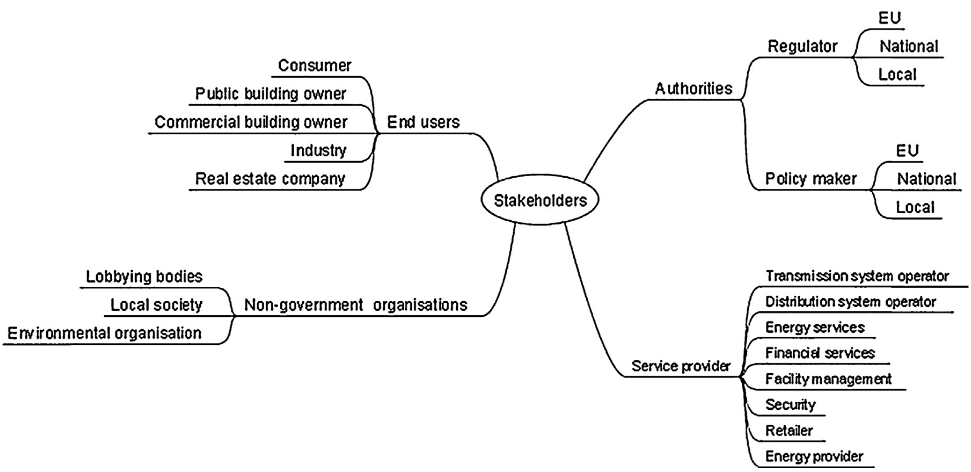


Fig. 1. Possible stakeholders having influence in districts' energy business.

Table 3
Actors in the energy market and their roles.

Actor	Role
Consumer	To consume energy, buys energy from energy retailer.
Producer	To produce energy, sells energy to energy retailer.
Prosumer[a]	To consume and produce energy, buys energy from an energy retailer.
Energy retailer	To buy and sell energy. Since a retailer cannot trade on the power exchange market, the retailer buys energy from a BRP. The retailer also pays fees to the BRP to cover imbalance risks.
BRP (Balancing Responsible Party)	To trade on the power exchange market on behalf of members of its portfolio, among energy retailers. BRP's that are out of balance are charged costs by the TSO. A BRP may have own power plants or trade energy on behalf of power generation parties.
DSO (Distribution System Operator)	Is responsible for the distribution of electricity, i.e. reliable and efficient operation of medium to low-voltage distribution systems. To prevent overcapacity on (parts of) the grid, the DSO is interested in peak shaving.
TSO (Transmission System Operator)	Is responsible for the transmission of electricity i.e. reliable and efficient operation of high and very-high voltage transmission systems.

[a] Energy consumer and/or producer.

of the questionnaire study were taken into account when making the list of possible business and service concepts in Section 4.

4. The cookbook – a collection of business concepts for Energy hub systems

The cookbook is a collection of proposed potential business concepts for Energy hub systems. These concepts were kept clear and simple by focusing on one service or product between one seller and buyer at a time. The following business concepts were suggested for Energy hub systems:

Business concepts for offering flexibility in energy demand and supply (1–5):

1. Flexibility for energy retailer's portfolio management.
2. Flexibility enabling maximised utilisation of locally produced energy.
3. Flexibility for local network management enabling maximised renewable energy supply.
4. Flexibility for balancing services to the balancing responsible party and transmission system operator.
5. Flexibility for local balancing at district level.
6. **Co-operative ownership of district heating network.**

Business concepts for energy service providers (7–9):

7. Energy broker buying and selling energy.
8. Flexible energy tariffs for (residential) consumers.
9. ESCO minimising customers' energy bills and optimising energy usage.

Business concepts for energy producers and energy companies (10, 11):

10. Heat storage utilised in district heating and/or cooling.
11. Flexibility in electricity network by heat pump to avoid peak power.

Business models for new roles (12, 13):

12. Heat recovery of excess heat utilised in district heating and cooling.
13. Prosumer selling self-produced energy.

These single business concepts can be combined into broader service offerings and business networks. For a specific district energy case, the selection of potential business concepts depends on the benefits striven and value captured in the case. Table 4 presents the value captured/expected for main stakeholder groups in different business concepts. The table is only indicative and made for concepts 1–13 described in this paper.

The stakeholders, interactions and information needed for evaluation of the cases are presented in tables and figures describing the specific business concepts in more detail. The evaluation of the costs and benefits and economic viability of business models depends on the specific case and details of the model. Two examples are of these are presented.

4.1. Example of a business concept: an energy broker

As an example of suggested business concepts, an energy broker service concept is presented in Table 5. The concept and its stakeholders, interactions and data needs are visualised in Fig. 2.

Table 4
Expected benefits and value for different stakeholders by using the models. Numbers in the table refer to business concepts mentioned above.

Stakeholders	Retailer	Broker	Producer of RE	Distribution system operator	Balancing responsible party	Transmission system operator	Local balancing party	Consumer	Prosumer	Producer	Energy storage owner	Excess heat owner	Heat service provider	ESCO	Society
Value to capture															
Energy balancing management	1, 10, 12	1			4	4									
Management of selling and buying	1, 10, 12	1													
Flexibility/demand response services	1, 10, 12	1	2	3	4	4	5								
Energy cost savings	8, 10, 12							1–6, 8, 11	1–6, 8, 13				10		
Good price for energy	8, 10, 12		2						1–6, 8, 13	1–6, 8	10	12	6, 11	9	
Use of local energy															2, 5
Easy energy services								7, 9	7	7	7				
Lower emissions															1–13

Table 5
An example of a suggested business concept: energy broker buying and selling energy.

Title	Energy broker buying and selling energy
Business idea/objective	An energy broker trades energy (electricity, gas, heat, cooling) on behalf of its customers on the wholesale market, from energy storage or from its customers, which can be either prosumers with small-scale energy production (e.g. PV on a zero energy building) or larger energy production facilities. A broker needs to manage his purchases and sales of energy (longer term markets, day-ahead, and intraday markets can be considered). An energy broker can also employ the energy consumption flexibility of its customers in its portfolio management.
Offer/value proposition	Easy energy service for customers: selling and buying of energy on their behalf, and aim to minimised energy bills for energy consumers and maximised profit for energy producers. Broker may use market mechanisms (as the power exchange) to optimise prices based on demand and supply.
Customer	Energy consumers and prosumers, who do not want to take care of the energy retailing by themselves. Energy producers and owners of energy storages.
Seller	Broker sells the brokering service for customers to buy and sell energy on their behalf.
Earnings/revenue model	Broker targets to optimise their portfolio by maximising the margin between energy purchases and sales and minimising their risks to improve their competitive position. Broker's earnings come from: (1) agreed percentage of the consumers' energy savings (in exchange for minimising the energy bill); (2) agreed percentage of the energy sold on behalf of the prosumers and producers (in exchange for targeting the best possible energy selling price).
KPIs	Economic feasibility for the different stakeholders involved, emission savings.
Costs and benefits	Benefits: better margin between purchases and sales for the customers – retailer gets a certain percentage of this margin. Costs at district level: Server; Communication infrastructure; Energy management system for a broker; and Prediction of energy demand and local renewable energy supply. Costs at house level: Gateway; User interface (web page, display); Smart meter; Smart appliances / storage (optional); and Communication infrastructure.
References	The concept idea is modified from Refs. [8,9]

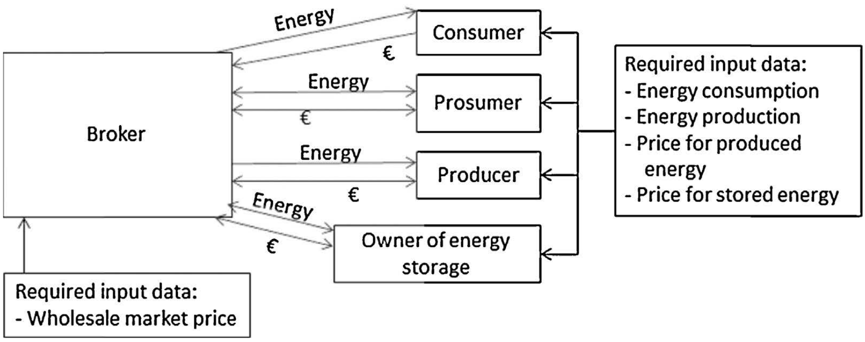


Fig. 2. Stakeholders, interactions and data needed for an energy broker buying and selling energy.

Table 6
An example of an integrated business concept: full service provider.

Title	Full service provider
Business idea/objective	Full service provider enables carefree and easy energy and facility service management for his customers by providing optimal indoor conditions in customers' facilities with necessary facility management services, including e.g. energy brokering and energy management. Full service provider offers information services for clients. Energy service provider has co-operation partners.
Offer/value proposition	Easy energy service for customers: high quality indoor conditions and energy management. (This includes e.g. selling and buying of energy, energy brokering management, and demand side management. Management, operation and maintenance of customers' energy systems. Designing, planning and construction of the energy systems, and supporting to manage the financial investment arrangements of the energy systems. Facility management and other necessary services.)
Customer	Customers that need complete, easy and carefree energy solutions with high quality performance of indoor conditions, energy solutions, energy efficiency, and secondary facility management services. E.g. prosumers, such as owners of net zero energy buildings or other energy providers. Customers willing to offer their flexibility or overproduction.
Seller	Full service provider, who organises subcontracts with other partners, e.g. energy solution designer, facility management company, energy delivery company and investor/financing partner.
Earnings/revenue model	General model: Seller of services earns money from energy efficiency, and/or creating flexibility that he sells to other stakeholders.
KPIs	Economic feasibility for different stakeholders involved. (Primary) energy and emission savings. Service level offered is measured by defined KPI, depending on service.
Costs and benefits	Same as for energy broker in Table 5. Additional costs: investments to energy efficiency and renewable energy equipment, maintenance costs, design and operation costs. Additional benefits: improved operation and maintenance, optimised investments to the energy system and equipment.
References	Some of these services are implemented in Finnish Kaivomestari School case in Espoo [4, p. 66–68].

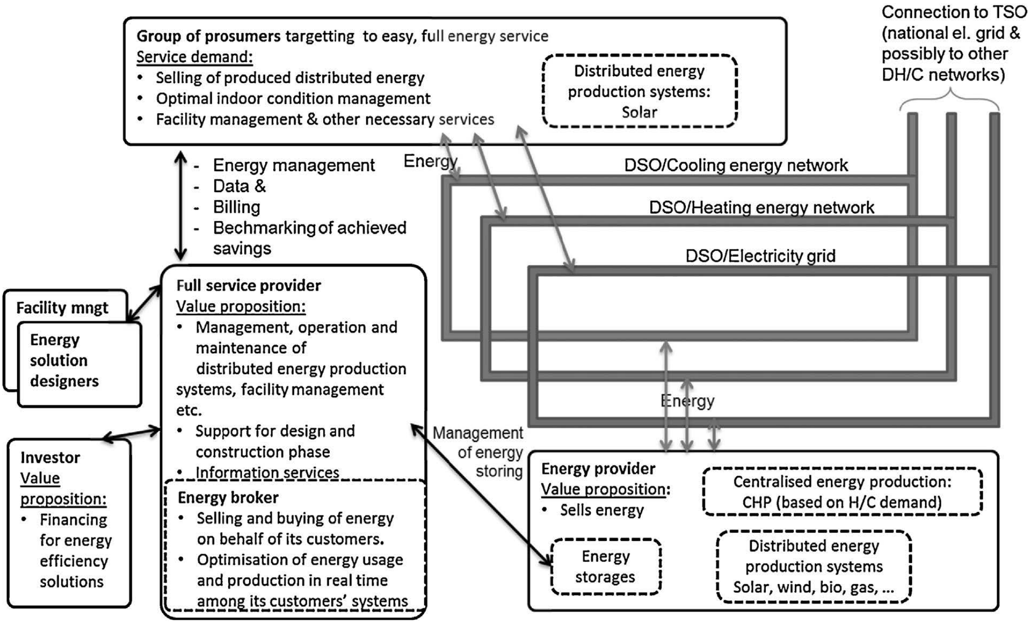


Fig. 3. An example of a network of actors co-operating with full service provider in an Energy hub district.

4.2. Example of an integrated multi-actor concept

A list of suggested business concepts was presented in Section 3.1. These concepts can be integrated into specific Energy hub systems. An example of such combination of is a full service provider concept presented in Table 6. The operation environment and involved stakeholders are presented in Fig. 3. This model is a combination of following business concepts:

- Flexibility for energy retailer's portfolio management (#1)
- Flexibility for local balancing at district level (#5)
- Energy broker buying and selling energy (#7)
- Flexible energy tariffs for (residential) consumers (#8)
- ESCO minimising customers' energy bills and optimising energy usage (#9)

4.3. Energy system business concept for a Dalian case study in China

One of the studied Energy hub case areas is located in a new district under planning in Dalian city in the Northeast China. The total planning area provides housing and services for 100 000 inhabitants, and in addition there are significant space reservations among others for office and industrial buildings. The studied Dalian case area is a partial neighbourhood selected from this new planning area. The studied area includes 103 700 m^2 (see Fig. 4) and consists of high rise residential buildings, schools and mixed commercial and residential building. As social, economic and technological aspects are different from the other European cases, the Dalian case will show special features and open new views to the Chinese energy market.

The base line for the energy planning is the local building code requiring 65% energy savings for buildings. Energy system will be supported by ICT technologies, such as smart energy management, and hybrid energy sources will be used. The planned energy concept is based on mainly on CHP production. The peak heating demands will be covered with a heat boiler. Additional heat sources are (1) a heat pump using sewage or seawater as a heat and cold energy source, (2) solar thermal collectors and (3) the external district heating grid as a reserve option. The electricity will be bought from the national grid.The following potential business concept elements were identified suitable for the Dalian case:

1) **Business concepts for offering flexibility in energy demand and supply**
   - Flexibility for local network management enabling maximised renewable energy supply (3.)
   - Flexibility for balancing services to the BRP/TSO (4.)
2) **Business models for new roles**
   - Prosumer selling energy of own distributed energy production (13.)
   - Heat recovery of excess heat utilised in district heating and cooling (12.)
3) **Business concept for energy producers**
   - Heat storage utilised in district heating (10.)

Potential new energy business opportunities were hence identified for local and national energy operators offering flexibility services for balancing the electricity grid and maximising the renewable energy supply. Heat storage options could also play a significant role in this. From the energy consumers point of view, building owners and facility managers could be interested about new income possibilities from operating buildings as prosumers and selling distributed renewable energy to the grid. Furthermore, large energy consumers could utilise heat recover and selling of the excess thermal energy to district heating and cooling network.

5. Barriers for new Energy hub business and services

The implementation of the new business concepts requires profound evaluation of risks and success factors of the cases. Systematic risk recognition and assessment is needed for

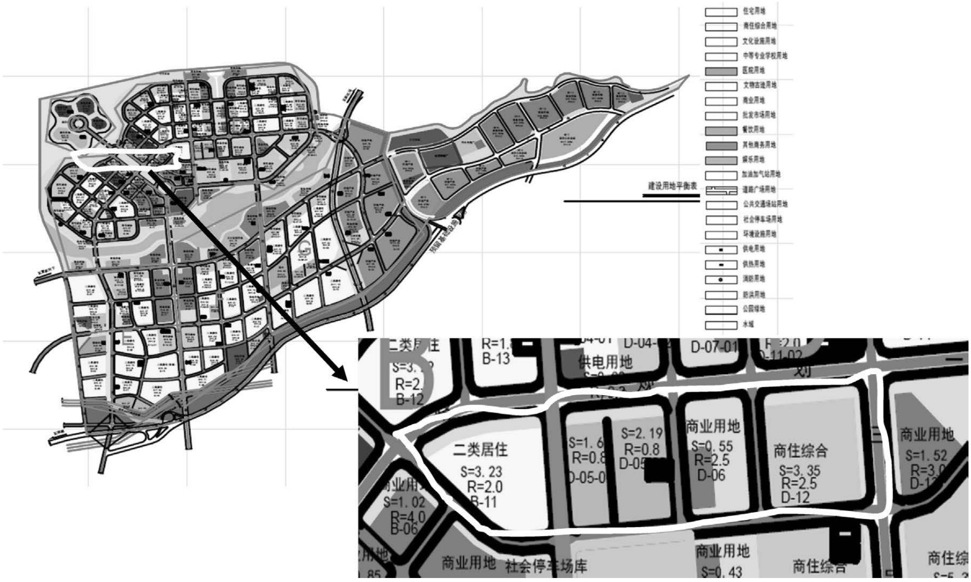


Fig. 4. Illustration of the studied Dalian case area and its location in the whole district master plan. *S* is the land area [10^4 m^2], and *R* is the ratio of building area to land area. Figure modified from Ref. [10].

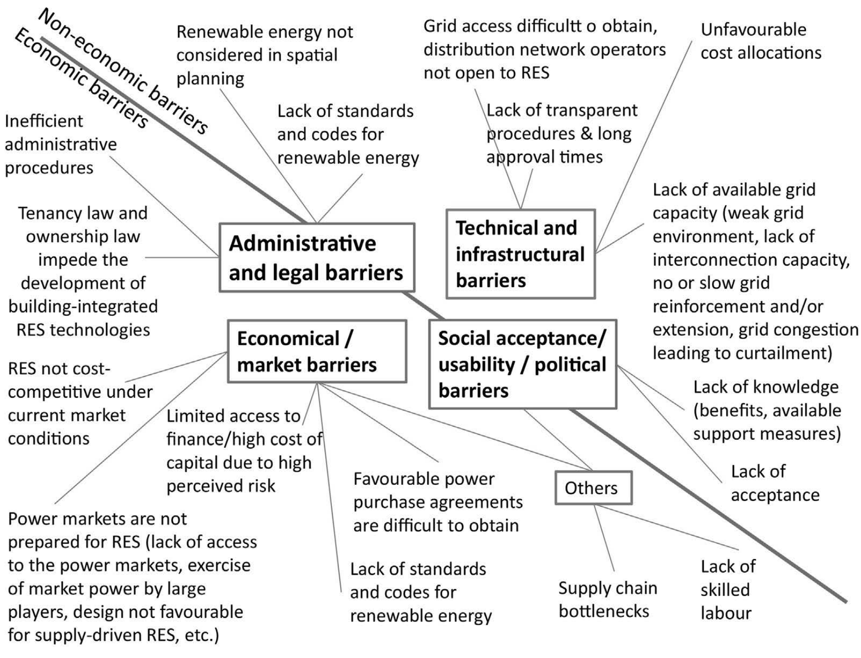


Fig. 5. Barriers for renewable energy related Energy hub businesses and services.
Summarised from Ref. [13].

managing risks and pinpointing the responsible party. The stages of risk analysis are defining the target, recognising hazards, assessing consequences, calculating probabilities, assessing the total risk, and finally, removing, reducing, and preventing the risk. The parties involved in the implementation of the business concepts are assessed for their ability to take responsibility for the risk, and usually, the responsibility is given to the party that could handle it best and to which it naturally belongs to. One possible approach for risk evaluation is a risk matrix or checklist approach with listing all the risks and then sharing these for stakeholders [11]. The detailed analysis is very case sensitive and requires detailed information about the case.

In general, it is good to know the barriers for new business concepts. The evaluation of barriers for new Energy hub business and services was done through a literature review. The main barrier groups for renewable energy systems by [13] are presented in Fig. 5. Identified barriers have been divided into economic and non-economic barriers, and into four categories: administrative and legal barriers, technical and infrastructural barriers, economic and market barriers and social acceptance and political barriers.

It is argued by [12], however, that new energy services business will overcome many traditional barriers, such as the need for a carbon emission price or disconnecting the profitability of an energy company from the energy volume growth. This will align the interests of many stakeholders, such as municipalities, end users, and energy service providers. Although there are several paths to create such energy service concepts, it is noted that the property sector, e.g. housing organisations, have presumably a significant role in finding new alternative options for organising the supply of services. In this case, new service concept would be based on repackaging product and service combinations based on consumers' needs. This can be called as a result or need oriented service model. Technologies needed for Energy hub system exists already, but for the wide-scale roll-out they have to be repacked in a new way, resulting in improved energy efficiency and reduced primary energy demand and related emissions [12].

6. Conclusions and discussion

Current district energy system research focuses on developing smarter energy systems with high share of distributed and renewable energy supply. This work focuses on Energy hub systems, which maximise the share of renewable energy with required information exchange at the district level with system integration and communication among all relevant stakeholders. Many of the needed energy technologies exits already, and hence one of the main challenges currently is to find the best possible business models for arranging energy business and services in each specific district.

This paper presents the development process and proposes potential energy service and business concepts for Energy hub systems. The method is modified from the Osterwalder approach taking the most crucial elements in the analysis. For each business concept, the main elements presented are the key objectives and the main idea. In addition, the offering and value proposition of the model is given with describing the roles of the main stakeholders (seller and buyer). In addition, the earnings and revenue model is presented and key performance indicators metering the success of the model are identified. The evaluation of the costs and benefits is a key element.

Business concepts are kept simple and focusing only to one seller-buyer service or product concept at a time. In practical cases the business and service model is often a combination of these cookbook business concepts.

Many of the proposed business concepts are based on the assumption that energy consumers and producers have a certain amount of flexibility in their energy demand and supply. This flexibility is a new aspect in the energy market and it is a commodity that is used to create new business concepts.

It must be noted that legal framework can set barriers for the actual implementation of proposed new business concepts. As an example, there can be legal issues related to the competition of contracts and offered energy services. In addition, some models can require such information that is not publicly available due to data privacy conservation, such as individual consumers' real time energy consumption data. There are ways to solve these issues, e.g. an energy company can contractually agree with its customers to access and utilise the individual energy consumption data.

Currently only some of the proposed business cases are easily feasible today (at least the following concepts: 1, 2, 6, 8, 9, 10, 11, and 12). Quite many of the proposed concepts have actors and roles that do not widely exist yet. For demonstrating a new business concept, one often needs to have a new company. Even if it is possible to demonstrate for example an energy broker tool as a use case, there is still a need for a neighbourhood energy services operator, which does not exist today. There is need for demonstration cases giving measured data of the success of the business models.

Acknowledgments

This work is a part of the European Commission funded project called E-Hub: Energy-Hub for residential and commercial districts and transport (grant agreement no: 260165). The project is funded under the specific programme "Cooperation" in the FP7 framework initiative "Energy efficient Buildings (EeB, FP7-2010-NMP-ENV-ENERGY-ICT-EeB)". All E-HUB project partners are acknowledged, including especially Kris Kessels from VITO; Mieke Oostra, Cor Warmer, and Frans Koene from TNO, Reijo Kohonen from Global EcoSolutions Ltd, Paola Laiolo from ISPE, Mauro Alberti from CESTEC, and Bronia Jablonska from ECN.

References

[1] eHub Project: Energy-Hub for Residential and Commercial Districts and Transport. Project Website: http://www.e-hub.org/ (accessed 20.01.14).
[2] EU Commission, Promoting Innovative Business Models with Environmental Benefits. Final Report, 2008, November, 118 p.
[3] A. Osterwalder, Y. Pigneur, Business Model Generation, John Wiley & Sons, Inc., Hoboken, NJ, 2010, ISBN: 978-0470-87641-1.
[4] I. Heimonen, M. Sepponen, et al., D6.1. Description of Market Needs and Business Models in Area of District Level Energy Services. eHUB Project Report, 2012, http://www.e-hub.org/pdf/D6.1_Market_needs_and_business_models_in_district_energy.pdf (accessed 23.01.14).
[5] IDEAS "Intelligent Neighbourhood Energy Allocation & Supervision". Project Website: www.ideasproject.eu/ (accessed 23.01.14).
[6] Ambassador Project: Autonomous Management System Developed for Building and District Levels. Project Website: http://ambassador-fp7.eu/ (accessed 23.01.14).
[7] EEPOS Project: Energy Management and Decision Support Systems for Energy POSitive Neighbourhoods. Project Website: http://eepos-project.eu/ (accessed 24.01.14).
[8] F. Cricchio, et al., Deliverable 2.2.2: Structured Approach to Cases. IREEN Project: ICT Roadmap for Energy Efficient Neighbourhoods. Project Report, 2013 http://www.ireenproject.eu/wp-content/uploads/2012/09/IREEN_D2.2.2_Structured_Approach_to_Cases_V1.0.pdf (accessed 23.01.14).
[9] Integral Project: Integrated ICT-platform based Distributed Control in Electricity Grids. PowerMatcher/Intelligator Development. http://www.integral-eu.com/ (accessed 23.01.14).
[10] The new district plan in Dalian, China. Original plan map from Dalian University of Technology. Discussions with Professor Lin Duanmu 端木琳 and rest of the research team. School of Civil Engineering, Faculty of Infrastructure Engineering. Dalian University of Technology.
[11] I. Heimonen, I. Immonen, T. Kauppinen, M. Nyman, J.-M. Junnonen, Risk management for planning and use of building service systems, in: CLIMA 2007 Well being Indoors, 9th REHVA World Congress, 10–14 June, Helsinki. Proceedings, vol. 3. FINVAC ry, 2007, pp. 485–494.
[12] A. Szatow, G. Quezada, B. Lilley, New light on an old problem: reflections on barriers and enablers of distributed energy, Energy Policy 43 (2012) 1–5.
[13] C. Klessmann, A. Held, M. Rathmann, M. Ragwitz, Status and perspectives of renewable energy policy and deployment in the European Union—what is needed to reach the 2020 targets? Energy Policy 39 (2011) 7637–7657.

Appendix E: Paper V: Energy planning of low carbon urban areas - Examples from Finland

Hukkalainen Mari, Virtanen Mikko, Paiho Satu, Airaksinen Miimu. Sustainable Cities and Society, vol. 35, pages 715–728. Copyright 2017 Elsevier Ltd. Reprinted with permission from Elsevier. https://doi.org/10.1016/j.scs.2017.09.018

Sustainable Cities and Society 35 (2017) 715–728

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Energy planning of low carbon urban areas - Examples from Finland

Mari Hukkalainen (née Sepponen)*, Mikko Virtanen, Satu Paiho, Miimu Airaksinen

VTT Technical Research Centre of Finland Ltd, P.O. Box 1000, FI-02044 VTT, Finland

ARTICLE INFO

Keywords:
Urban planning
Energy analysis
Energy demand
Energy supply
Transport planning
CO_2 equivalent emission

ABSTRACT

During urban planning, city planners and municipal authorities make various choices that impact districts' energy efficiency and emissions significantly. However, they often lack information about the actual effects of the design options. This paper describes a methodology, embedded to a tool called Kurke, that aims to support the planning of sustainable and energy efficient urban areas by analysing the energy performance of city plans and the impacts of their energy design alternatives on carbon dioxide emissions during planning. The methodology supports holistic energy analysis of urban areas, including energy demand of buildings and transport, and comparing 10 alternatives for local energy supply. The methodology is tested in two Finnish residential and mixed-use areas. The improved transportation plans can reduce CO_2 emissions 10–20% compared to the business-as-usual design in case areas. CO_2 emissions from buildings' heating can be reduced 18–24%. The total CO_2 reduction potential of urban planning choices varies from 2% to 78% in case areas. This shows the significant role of urban planning in reducing CO_2 emissions. Therefore, it is important that urban planners understand the impacts of the design decisions. Kurke tool offers such support with fast and practical evaluation of the planning options.

1. Introduction

Government of Finland has updated its national energy and climate strategy in 2013 (Finnish Government, 2013) and again in 2017 (Ministry of Economic Affairs and Employment, 2017) to ensure the achievement of the national targets for 2030 and to prepare a path to the long-term energy and climate objectives set by the European Commission for low-carbon economy in 2050 (European Commission, 2011). Similarly, many European countries have national strategies and targets for reducing energy demand and increasing energy efficiency and renewable energy use, as described e.g. by Brandoni and Polonara (2012) and Sperling, Hvelplund and Mathiesen (2011). The realisation of these urban energy planning targets and strategies requires both national and city level commitment (Neves & Leal, 2010), and its success depends on the satisfaction of the involved stakeholders (Ouhajjou, Loibl, Fenz, & Tjoa, 2017).

Municipal authorities play a key role in affecting local CO_2 emissions through decision making and various development actions, including urban and transport planning and used energy sources (Neves & Leal, 2010). For example, municipalities can promote the use of renewable energy through urban plans and building permits. The challenge of enhancing energy efficiency is an extremely relevant topic for planning at the municipal level (Poggi, Firmino, & Amado, 2017). Energy efficiency can be increased by raising the awareness of residents and guiding stakeholders on how to improve city's infrastructure, systems, and building performance (Mickwitz, Hilden, Seppälä, & Melanen, 2011; Monni & Syri, 2011).

Urban planners can significantly contribute to shape energy-efficient and low-carbon cities, and the development of appropriate solutions requires close collaboration between researchers and practitioner (Cajot et al., 2017). Urban planning decisions define the land use and the layout of the area, the scale and the type of buildings, and specifications o transportation and other urban networks (Yeo, Yoon, & Yee, 2013). Urban and spatial planning and the energy system planning should be closely linked together early on the urban planning process, because the energy consumption and potential local energy sources are strongly connected to the urban plans (Zanon & Verones, 2013). Examples of the planning decisions affecting often also to the energy systems of the district include the location of services, links to the existing (regional) urban infrastructure, the size and the form of transportation networks and accessibility to jobs and services. Close collaboration between the energy planning and urban planning can also provide a fruitful source for innovative local energy policies (Gabillet, 2015).

One of the challenges municipalities are facing is the need to be prepared for future changes in energy demand and supply in the long term. The paradigm shift in energy systems is starting with increasing the amount of distributed generation (Manfren, Caputo, & Costa, 2011).

* Corresponding author.
E-mail addresses: mari.hukkalainen@vtt.fi, mari.hukkalainen@iki.fi (M. Hukkalainen (née Sepponen)).

http://dx.doi.org/10.1016/j.scs.2017.09.018
Received 18 April 2017; Received in revised form 14 September 2017; Accepted 17 September 2017
Available online 19 September 2017
2210-6707/

At the same time, the energy demand of buildings is expected to decrease, among others due to European Commission's Directive on energy performance of buildings for adopting highly efficient nearly zero energy buildings (Official Journal of the European Union, 2010). An EU strategy on heating and cooling (European Commission, 2016) promotes the deployment of renewable energy in district heating and combined heat and power production (CHP), while other energy and climate targets aim to increase the use of renewable energy sources in general. In this transition towards sustainable energy systems, demand side management and energy balancing have also an important role to assure the efficient use of renewable energy and match the energy supply to the demand (Manfren et al., 2011; Pina, Silva, & Ferrão, 2012). Due to these changes, it is increasingly important that energy efficiency, renewable energy and holistic energy planning are taken into account in cities' urban planning strategies. In fact, urban planning is an effective tool for enhancing sustainable development and developing of energy efficient cities (Amado, Poggi, & Amado, 2016). The pressing of issues related to energy could enable rethinking of how novel quantitative solutions, including tools for urban scale simulation and optimisation, could be used to inform planning (Cajot et al., 2017).

2. Methodology

2.1. Objectives of the research method

The research presented in this paper aims to bring a new insight for sustainable and energy efficient urban planning by developing a practical methodology and a tool for assessing energy and carbon impacts of urban areas during the planning process. The main research problem studied in this paper is: *how Finnish urban planners can be supported in designing energy efficient districts with low carbon emissions*? The objective of this research is to develop a methodology for *fast and practical assessment and comparison of urban plan alternatives and their impacts on energy efficiency and CO_2 equivalent emissions*. The methodology consists of assessing the energy demand of an urban area plan, including buildings and passenger traffic and comparing potential energy supply alternatives and their CO_2 emissions. The methodology is tested in two Finnish real life urban planning cases located in the Helsinki Metropolitan area. This methodology is implemented in the Kurke tool, which is available online (Sepponen, Virtanen, & Lahti, 2012) (in Finnish), and its usage is guided in a research report by Lahti, Sepponen and Virtanen (2012). The Kurke tool is meant to be used in the development of municipal master plan and detailed plan, as marked in Fig. 1, which provides the overall hierarchy structure of the Finnish urban planning process.

This research was composed of five main elements:

1) Identifying Finnish urban planners' and other experts' needs and requirements for low carbon urban planning and its relation to energy systems (Section 3).
2) Developing a methodology, embedded in the Kurke tool, for district energy and emission analysis to support urban planning (Section 4). This methodology included assessing energy demand of buildings (section 4.1) and transport system (Section 4.2) and comparing available energy supply options to traditional design (Section 4.3).
3) Identifying two Finnish urban planning cases to be used as test cases, including collecting the base information of the case areas and the assessing the requirements and boundaries for the energy supply analysis (Section 5).
4) Testing the methodology and Kurke tool by performing an analysis of district energy and CO_2 emission related impacts of design alternatives in selected cases (Section 6).
5) Testing the Kurke tool with the urban planners (Section 6.5), and finalising the tool based on their feedback.

3. Urban planners' needs for ideal urban energy plan

3.1. Existing tools for assessing districts and their sustainability

There exists already different tools for assessing urban environment and its sustainability, such as BREAAM Communities (BREEAM, 2012), CASBEE for Urban Development (Institute for Building Environment and Energy Conservation (IBEC), 2014) and LEED for Neighbourhood development (US Green Building Council, 2009), as well as SBTool2012 and GBI for Township, of which all others besides SBTool2012 have been developed based on national standards as a reference (Charoenkit & Kumar, 2014). Other urban area assessment tools related to energy system have also been developed e.g. (Amado et al., 2016; Hedman, Sepponen, & Virtanen, 2014; Mourmouris & Potolias, 2013). Most of these tools are targeted for evaluating the urban plans and the neighbourhood level. Regional level green energy planning tools also exists, mostly using mathematical modelling approaches (Bhowmik, Bhowmik, Ray, & Pandey, 2017). For example, an regional energy system model has been developed in Italy (Cormio, Dicorato,

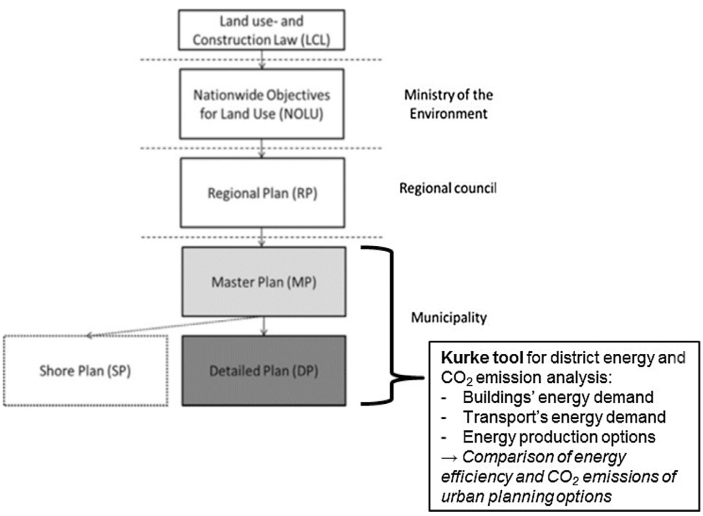


Fig. 1. Urban planning process in Finland and the application area for the developed Kurke tool (FINLEX, 1999, as cited in Hedman et al., 2014).

Table 1
Existing district level sustainability assessment tools and their estimated exploitation potential to support low carbon urban planning in Finland.

Tool	Scope	Exploitation potential in Finland	Reference
BREEAM-Community	New development at neighborhood scale: Buildings and their impacts on transport, land-use, economic and social characteristics.	Potentially suitable; mainly for evaluating the final result of new development.	Charoenkit and Kumar (2014), BREEAM (2012)
LEED-ND	Neighborhood development; smart growth, urbanism and green building.	Potentially suitable; mainly for evaluating the final result.	Charoenkit and Kumar 2014, US Green Building Council (2009)
CASBEE-UD	Assessment method for multiple buildings and other elements on a large-scale site.	Developed for Japanese environment. Mainly for evaluating the final result.	Charoenkit and Kumar (2014), Institute for Building Environment and Energy Conservation (IBEC) (2014)
SBTool2012	Designed for different development stages and locations, different sets of criteria and indicators. User weights the criteria.	More complicated to begin than BREAAM, CASBEE, LEED, but allows setting local prioritisation.	Charoenkit and Kumar (2014)
GBI for Township	Sustainable building development in Malaysia.	Completely different climate & environment	Charoenkit and Kumar (2014)
A theoretical model and its practical application	Balance energy consumption of districts and PV potential in districts for a whole city.	Buildings included, not transportation. Only PV supply, no other RES or CHP.	Amado et al. (2016)
A theoretical model and its practical application	Balance energy consumption of districts and PV potential in districts for a whole city.	Buildings included, not transportation. Only PV supply, no other RES or CHP.	Amado et al. (2016)
A bottom-up energy system optimisation	Support planning policies to promote RES. Primary energy, power & heat, emissions and end-uses.	Planning of regional energy systems, not for urban planning. Includes regional CHP	Cormio et al. (2003)
Evaluation framework & multi-criteria decision analysis	A multilevel decision-making structure, multiple criteria for energy planning and optimal RES of at the regional level.	Supports decision-making for regional RES. Larger level than district; no transport planning scenarios.	Mourmouris and Potolias (2013)
An land use-transport-energy model for future smart cities	Developed for future smart cities. Spatial explicit land use model. Assesses the possible RES implications.	Potential. Developed for Tokyo, focus mostly on megacities development.	Yamagata and Seya (2013)

Minoia, & Trovato, 2003). There also exists various models for optimising district heating and cooling systems (Sameti & Haghighat, 2017). In general, LCA approach emerges as a promising framework for the environmental assessment of a territory (Loiseau, Junqua, Roux, & Bellon-Maurel, 2012). There are also methods for setting the targets for the local energy planning, which guide to act toward global climate change mitigation and other policy objectives (Leal & Azevedo, 2016). A summary of the tools that could support low carbon urban planning is presented in Table 1 with an estimation of their exploitation potential in Finnish urban planning.

3.2. Survey for Finnish urban planners and other planning experts

The authors performed an online survey to map urban planners' and other urban planning experts' needs and requirements for sustainable urban planning in Finland in 2012. This stakeholder requirement survey had in total 19 respondents, of which 9 persons represented the municipal and public sector and 10 persons were from the private sector.

Survey respondents were asked as an open question, what an ideal urban energy plan should include in their view. The following list summarises stakeholders' requirements for the ideal urban energy plan:

- Overall strategy first, then suitable means accordingly.
- Holistic design and sustainability impact assessment requires collaboration and interaction.
- Evaluating of the most crucial issues with biggest effects on energy demand and emissions.
- Energy efficiency as a target already from the beginning.
- Targets for the energy efficiency, emissions and the share of renewable energy.
- City plan enabling broadly different energy supply means, both centralised and distributed energy.
- Urban planners to choose with experts the most suitable energy options for each area.
- Defining of allowed energy production means and their placement.
- District heating and cooling data included in the urban plan: energy sources and their emissions.
- If district heating available, then it needs to be prioritised and only more efficient sustainable options would be allowed.
- In district heating areas: focus only on producing electricity in the buildings.
- Effective transportation network planning with high quality public transport, bicycling and walking.

The survey respondents were asked to write open comments about defining the energy efficiency in municipal urban development and construction projects. They wrote that it is important to consider and manage the whole entity of urban development, and one of the respondents wrote that currently "the entities of municipal construction projects are defined and managed very weakly". In addition, it was asked that what are the topics where you need more information about energy efficient planning, and for this the respondents listed that they need more information primarily about managing the whole system, and what changes have the biggest impacts. When asking that should the analysis tool consider only new areas under planning, and also, or only, infill and renovation areas, all respondents chose that a tool should be usable for both new and renovation areas.

78% of the respondents felt that there is a need for both energy efficiency assessment tools, and certifications for the assessed cases if passed by the tool. Most popular energy efficiency assessment tools that the representatives had used previously were LEED (37% of representatives) and BREEAM (26%). In addition to these, individual respondents had been using a wide variety of different indicator frameworks, and case comparisons based on simulations and calculations. When asking how to present the results of sustainability analysis for urban areas, the respondents wrote that the results should be presented in a simple and clear graphical form.

This survey indicated that urban planners still feel that it is challenging to assess the effects of different design choices on the overall energy efficiency and CO_2 emissions of urban plans clearly enough. They wrote that they require analysis tools for justifying the best urban development choices both for the decision makers and residents.

Similar annotations have also been raised in the research. It is noted that cities have difficulties in effectively evaluating the best suitable urban energy planning concepts (Eicker, Monien, Duminil, & Nouvel, 2015). The local level needs improved performance-based planning practises and solutions for taking energy goals into account in the spatial planning and urban policies to achieve low carbon and energy efficiency goals (Zanon & Verones, 2013). Typically, sustainability assessment tools are used only after urban plans are finalised, but it would be beneficial to use the assessment indicators already during the planning phase (Wedding & Crawford-Brown, 2007). The localisation of the urban area assessment is crucial (Haapio, 2012).

Although there exists various tool already, it still seems that there are practical gaps in evaluating districts and their sustainability in Finland. The survey confirmed that urban planners still seem to need more support in their practical work to assess the energy efficiency and carbon impacts of urban plans. As a consequence, there was a need to develop a tool that can support Finnish urban planners to understand the energy and CO_2 emission related impacts of the planning choices. Therefore, the district energy and emission analysis methodology was developed and implemented in the Kurke tool.

4. District energy and emission analysis methodology and Kurke tool

An important requirement for the methodology developed was that it should be clear and practical. At the same time, the level of details and accuracy should allow a sufficient comparison of different design choices of the urban plan. Analysis was done as a statistic situation at the annual level. The method needed to include all the major aspects affecting to areal energy efficiency via urban planning, including the entire energy chain of a district (Kılkıs, 2014). Similarly to an integrated land use-transportation-energy model for future smart cities (Yamagata & Seya, 2013), we included in the district energy analysis: 1) energy demand of buildings, 2) energy demand of passenger transportation, and 3) different energy supply alternatives. Based on these steps, total district energy can be analysed and its alternatives compared (Fig. 2). The methods for analysing these three key elements have been described in the following Sections 4.1, 4.2 and 4.3.

The developed energy and emission analysis methodology was embedded to a tool called Kurke. Kurke tool was implemented in a spread sheet program, and it was targeted for urban planners. The aim was that urban planners could check fast the energy efficiency and emission related impacts of the planning options during the development of municipal master plan and detailed plan. Kurke tool consists of 5 spread sheets, of which 3 are visible for the user. In the first sheet, the user fulfils the basic information of the buildings (size, type, number of residents and average energy demand based on the age of the building: see details in Section 4.1), basic information of the district (e.g. areal efficiency and distance to services; see details in Sections 4.2 and 4.3), and the boundaries for local energy production options (e.g. maximum availability of the roof surfaces for solar energy production). On the second sheet, user can see visually the energy demand and CO_2 emissions for the studied planning option, calculated automatically based on the input data and according to the developed analysis methodology presented in the following sections. Third spread sheet guides user to estimate the buildings' energy demands based on the age of the buildings (as in Table 2 in Section 4.1). The remaining spread sheets are hidden from the user, and they contain the calculation of the results according to the developed methodology and the Finnish transport modal split statistics (Finnish national passenger transport survey, 2012).

4.1. Building energy demand analysis

The total energy demand of buildings was calculated by multiplying the net floor area of buildings with the average annual specific energy demands for heating, cooling and electricity (kWh/m^2). The average annual energy demands were calculated with the REMA calculation tool (Tuominen, Holopainen, Eskola, Jokisalo, & Airaksinen, 2014) for different Finnish building types from different periods and for very energy efficient buildings. The REMA tool has been developed for assessing the energy performance and the effects of various energy efficiency measures in buildings on the scale of the whole building stock of Finland (Tuominen et al., 2014). The calculated average annual energy demand values are shown in Table 2.

Based on the survey results, a selection was made to categorize buildings into six different types: new apartment buildings, existing apartment buildings, new detached houses, existing detached houses, public and service buildings, and office buildings. This classification enabled assessing most typical residential and service areas in Finland. In addition, the analysis method included studying the effects of adding smart meters into buildings. Smart metering system can provide real time information for residents about their electricity use. The smart metering system, if in use, was estimated to decrease the electricity consumption on an average 8% corresponding an average electricity saving (Neenan & Hemphill, 2008).

4.2. The analysis of passenger transport and its CO_2 emissions

In the passenger transport analysis, the energy demand and CO_2 equivalent emissions of the passenger transport were estimated based on the city plan. The amount of passenger transport (in person kilometres) depended on the location and the type of the district. The local area was defined by following attributes: the average areal density, typical residential building types, distances to the nearest bus stop or daily services, and the type and the location of the area in respect of the surrounding urban structures. The statistical data about passenger transport was retrieved from the National Travel Research (Finnish national passenger transport survey, 2012), including data about passenger kilometres per person per day and the modal split data for different types of locations and areas in Finland in 2010 and 2011. The modal splits show the passenger transport data for each transport mode (passenger kilometres per person per day). The modal split was calculated according to the urban plan, the areal characteristic information and the statistical data about passenger transport.

Next, the authors developed improved transport planning alternatives, which aimed to decrease the need for private cars through urban planning decisions. These planning choices and solutions consisted of separate cycle paths and good quality and secure parking places for bicycles, centralised car parks, train station in the vicinity of the district, well planned and safe public transportation, walking and bicycling routes. Shorter distances to daily services (shops, day care centres and elementary schools) also decreased the need of using private cars. The impact of average distance to the nearest super and hyper markets were also taken into account. The reference level of the improved transport planning design choices and following potential effects in the modal split were developed based on a study from Freiburg (Germany) (Daseking, 2009). Certain urban planning and design measures, such as strong promoting of public transport, can decrease the share of using private cars from 38% to 28% (Daseking, 2009). In Freiburg, the share of walking and biking was originally quite high

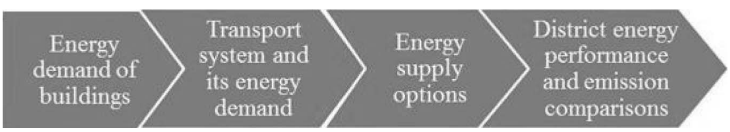


Fig. 2. Different phases of the analysis methodology.

Table 2
Average energy demands of different Finnish building types, calculated with the REMA tool (Tuominen et al., 2014).

Construction year	–1959			1960–1979			1980–2009			2010–2012			Very energy efficient		
Energy demand, [kWh/m^2,a]	Space heating/ Domestic hot water	Electricity	Cooling	Space heating/ Domestic hot water	Electricity	Cooling	Space heating/ Domestic hot water	Electricity	Cooling	Space heating/ Domestic hot water	Electricity	Cooling	Space heating/ Domestic hot water	Electricity	Cooling
Detached houses	158/45	53	0	165/43	53	0	102/41	64	0	51/39	57	0	25/30	57	1
Apartment buildings	154/49	38	0	162/46	39	0	99/44	45	0	30/39	36	0	25/39	36	0
Service and office buildings	234/49	130	10	242/46	135	10	179/44	155	10	65/42	105	0	30/42	105	0

Table 3
Average CO_2 equivalent emissions for different transportation modes in Finland (Modified from VTT Lipasto. Online database, 2009).

Average CO_2 equivalent emission factors in Finland in 2011	g of CO_2e/person-km
Private cars	98
City bus, 18 passenger/80 seats, diesel	59
City bus, 18 passenger/80 seats, natural gas	68
Local train (electric), 65 passenger/184 seats	22
Tram (estimated)	22
Metro (estimated)	22
Pedestrian (estimated)	9
Bicycling, etc. (estimated)	4

(50%), which could be taken as the target level in Finnish cities where the average is rather low).

The average modal splits were calculated for the business-as-usual and the improved transport planning scenarios in the studied urban plan. Based on this data, the authors calculated the annual CO_2 emissions of transport planning scenarios by multiplying the passenger kilometres with the average CO_2 emission factors for each transportation mode separately. The average emission factors for different transportation modes in Finland are listed in Table 3.

4.3. Analysis of energy supply options and their CO_2 emissions

To support urban planners in identifying potential energy supply options, the authors developed a predefined list of 10 different energy system alternatives. Two of these predefined energy supply alternatives represented the most common business-as-usual alternatives in Finland: district heating or electric heating (with buying the electricity from the national electricity grid). The recognition of the potential for renewable energy utilisation as a part of the district energy system is important, and hence, the remaining eight proposed alternatives included different renewable energy supply systems, such as ground source heat pumps, solar thermal collectors and photovoltaic panels. The predefined list of energy supply alternatives are shown in Table 4. For wind energy, it has to be noted, that its production depends highly on local wind conditions, and thus, this analysis evaluates the possible magnitude of wind energy supply. District heating can be either supplied from a local plant at the district, or from larger production units within the city. The most of the district heating in Finland is produced at CHP plants, from which the thermal energy is supplied through district heating network and electricity through the electricity grid (Statistics Finland, 2015).

For those urban areas that had a district heating system available, the heat distribution losses of the district heating network were added up to the total amount of needed heat energy supply. The typical average district heating network losses were estimated on the basis of the areal efficiency, with an assumption that districts with lower areal

Table 4
Predefined energy system alternatives.

Alternative	Thermal energy	Electricity
1	District heat	National grid
2	Electric heating	National grid
3	Ground source heat (decentralized)	National grid
4	Ground source heat (centralized)	National grid
5	Pellet boiler	National grid
6	Wood chip district heat	National grid
7	District heat	Photovoltaic + national grid
8	District heat & solar thermal	National grid
9	Wood chip district heat & solar thermal	National grid
10	District heat	Wind power + national grid

Table 5
The share of distribution losses from needed total energy production in areas with different areal efficiencies (e_a).

Type of the district	Areal efficiency (e_a)	Share of distribution losses [%]
Extremely Sparse	−0.1	18%
Sparse	0.1–0.2	12%
Average	0.2–0.3	9%
Dense	0.3–0.4	4%
Extremely dense	0.4 −	3%

efficiency tend to have longer heat distribution network in relation to the amount of energy demand required in the district. The estimated shares of the district heating losses for different types of areas were average values as listed in Table 4, mainly based on data from (Hedman et al., 2014; Nystedt, Sepponen, & Virtanen, 2012; Paiho et al., 2013) with supporting information from the corresponding Finnish municipalities of Jyväskylä, Jämsä, Petäjävesi, Multia, Kannonkoski, Toivakka, Helsinki, Sipoo, Kokkola, and Tampere. As Table 5 summarises, the distribution losses can be very significant in districts where the density of heat consumption is low, meaning sparse and extremely sparse areas where areal efficiencies are low (Hedman et al., 2014; Martikainen, 2013). Finnish Energy estimates that the distribution losses for a well-built and maintained network with a high consumption density are 6–8% (Energiateollisuus Ry, 2015).

When calculating the CO_2 equivalent emissions of different energy supply alternatives, the emission factors for average Finnish electricity and district heating were based on data from the Statistics Finland (Statistics Finland, 2015) and a Finnish district heating study (Keto, 2010). The other embedded CO_2 equivalent factors for specific energy production technologies were calculated with the GEMIS (Global Emission Model for Integrated Systems) software (International Institute for Sustainability Analysis and Strategy (IINAS), 2016). The used CO_2 equivalent emission factors and other information, such as assumptions used in the energy system analysis, have been presented in Table 6.

One specific characteristic of Finnish electricity production is the high share of CHP (Combined heat and power production), which represented 35% of Finnish electricity production in 2011 (Statistics Finland, 2015). The CO_2 equivalent emissions from CHP production between electricity and heat were allocated based on the efficiency of alternative segregated heat and electricity production methods. The typical efficiency of CHP plants is approximately 90% for heat production and 40% for electricity production (Keto, 2010).

5. Base data for two Finnish urban planning cases

5.1. Case areas

Two Finnish urban area plans were selected for testing the low carbon urban planning methodology. Both of these areas were typical Finnish real life urban plans located in the Helsinki metropolitan area. They represent different levels of the land use planning; the first area is a small new residential neighbourhood under development of a detailed plan, and the second area is a larger district, for which a master plan was being developed (see the land use planning levels in Finland in Fig. 1). The case areas were selected from the research partners' ongoing urban development projects in collaboration with the cities and urban planners, who were participating to the national research project for developing solutions for sustainable urban development in Finland.

The first case was a detailed plan of a new small neighbourhood (the layout of the area is shown in Fig. 3) located in Kivistö, which was one of the first construction areas in a new Marja-Vantaa district under development in the city of Vantaa. The first case area consists of six residential blocks, a public service building and a car parking area. The second case area was Eriksnäs (preliminary layout in Fig. 4), which is part of the Sibbesborg master plan located in the municipality of Sipoo. It had already existing buildings and a strong need for infill construction and development of the area. This case was in the early drafting phase, and the tool was used during the development of the urban plan, with using the preliminary information about the specifications for the urban plan. The second case area consisted of small neighbourhoods with blocks of apartment buildings and office buildings and blocks of detached buildings. Real time smart metering was planned for the new buildings. The areal density of Kivistö neighbourhood was planned to be almost double as high as in the Case 2 plan in Eriksnäs. Detailed specification of the case areas has been listed in Table 7.

5.2. Requirements, boundaries and input data for energy supply alternatives

The compared energy supply alternatives have been listed in Table 4, and additional 2 scenarios with multi energy sources have also been studied. The specific boundaries and potentials for local renewable energy supply calculations have been presented in Table 8. In both case areas, the total available roof surface set boundaries for the potential solar electricity supply. It was estimated from the city plan that approximately 50% of this roof surface would have been available for installing photovoltaic panels (PV) or solar thermal collectors.

Solar thermal collectors are typically designed according to the hot domestic water heating demand during the summer period when solar energy is available, enabling maximal efficiency for the investment. In Finland, this means approximately 7–8 months from March to October. During this period, approximately 50% of the total annual hot domestic water heating demand can be supplied from solar thermal energy. In

Table 6
The embedded CO_2 equivalent emission factors of different energy production systems (based on average values during the years 2000 and 2007 (Keto, 2010; Statistics Finland, 2015) and calculations with the GEMIS (International Institute for Sustainability Analysis and Strategy, 2016)). Electricity based heating systems are marked with *.

Energy production system		CO_2 equivalent emissions [kg/MWh]	Additional information and assumptions
Heat energy	District heating	217	Average in Finland.
	Electric heating*	Emissions of the electricity demand	Efficiency of electric heating system 100% (Ministry of the Environment, 2012b). Energy conversion factor for electricity is 1.7 (Ministry of the Environment, 2012a).
	Ground source heat pump*	Emissions from the electricity demand and the system manufacturing 9 kg/MWh	Annual coefficient of performance is 2.5 for heating.
	Pellet boiler	9	Fuel transported 100 km, emissions 0.11 kg/km
	Wood chip district heat	29	Fuel transported 100 km, emissions 0.02 kg/km
	Solar thermal	24	Production 391 kWh/m^2,a
Electricity	Electricity from national grid	274	Average in Finland.
	Photovoltaic panels	110	Production 110 kWh/m^2/a
	Wind power	58	1 wind turbine with the power of 1 MW, producing 1000 MWh/a.

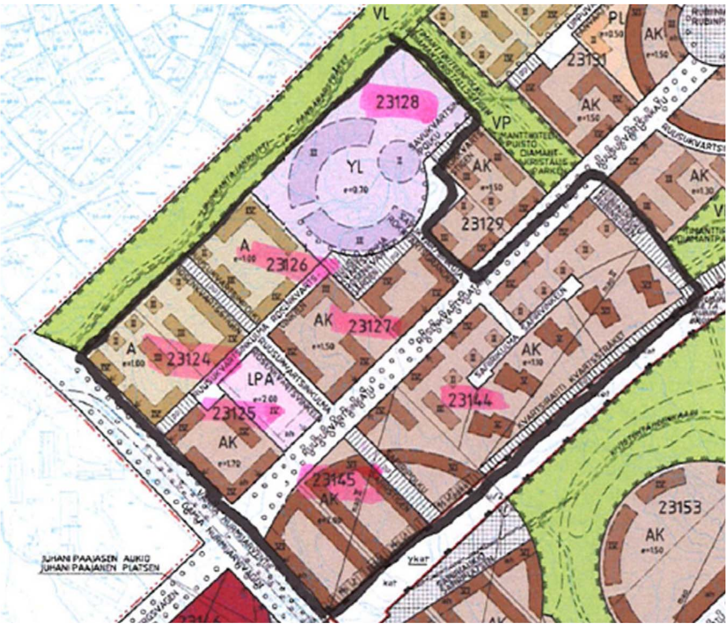


Fig. 3. Detailed plan of Kivistö in the City of Vantaa, Finland (modified from Marja-Vantaa city plan (Municipality of Vantaa, 2012)). The studied area is circulated in the figure. Markings in the plan: A is residential buildings, AK residential apartment buildings, VP and VL green areas and parks, LPA car parking space and YL public service buildings. The number series with five digits shows the number of the block.

Fig. 4. Draft of the master plan of Eriksnäs (modified from Eriksnäs city plan, 2012). The drafted new building blocks under planning are shown with as black blocks (grey blocks are already existing in the area). Blue areas are sea, green areas are parks and leisure areas, and yellow areas are cultivation fields.

both case areas, the heat demand of hot domestic water heating during summer period was the basis for calculating the maximum available solar thermal collector area and their potential energy supply, without producing excess solar thermal energy or using thermal energy storage. The average hot domestic water heating demands for buildings have been presented in Table 2.

Small scale wind energy supply was also included in the comparison as a theoretical option in both case areas. In the case 1, this was made by adding in total 1 MW of wind energy supply, which was produced with 5 small vertical axis wind turbines; and similarly in case 2 by adding 3 MW wind power capacity with 15 small wind turbines. The electricity yield of these small wind turbines was calculated based on 5 m height vertical axis wind turbine model called WS-4 manufactured by Windside, which produces approximately 2000 kWh/year with 5 m/s wind speed on average (Windside, 2016). The annual mean wind speed ranges from 5 to 6 m/s in the metropolitan area of Finland (Finnish Meteorological Institute, 2009).

In addition to the predefined list of energy supply systems (as listed in Table 4), two additional energy supply scenarios were analysed for both case areas. The first additional scenario was a district level heat pump providing annually approximately 90% of the total heat demand, and the rest 10% of heat was provided with electrical heaters. This scenario was chosen due to its lower investments costs, because this way the maximum capacity of the heat pump system could have been significantly lower (approximately 75% of the maximum heat capacity needed), than if the heat pump would have provided the entire heat

Table 7
Detailed description of urban location and type of case districts.

	Case 1: Kivistö	Case 2: Eriksnäs
Location	the metropolitan area	the metropolitan area
The population centre of the city area	Helsinki	Helsinki
Distance to the centre of Helsinki	21 km	30 km
Size of the area under planning	400 m × 314 m; 13 ha 7 building blocks	361 ha
Environmental characteristics	Field, no buildings existing.	Sparsely built; fields and forest; some existing buildings.
Total floor area	112,035 m^2	842,580 m^2
Total floor area of apartment buildings	92,025 m^2	690,180 m^2
Total floor area of detached houses	1810 m^2	52,400 m^2
Total floor area of service buildings	18,200 m^2	80,000 mB^2
Total floor area of office buildings	–	20,000 m^2
Number of inhabitants in the area	2100	16,000
Planned floor area per resident	45 m^2	49 m^2
Type of the area	urban area	village area
Areal efficiency[a]	more than 0.4	0.2–0.3
Number of new working places	–	1400
Traffic zone	local centrum	local centrum
Distance to grocery store	250 m	500 m
Distance to hyper market[b]	500 m	n/a
Distance to elementary school	300 m	500 m
Distance to small recreational spaces (< 1,5 ha)	300 m	within the area
Distance to large recreational spaces (> 20 ha)	not inside the area	within the area
Distance to most used public transportation stop	100–300 m	100–300 m

[a] The total floor area of buildings per the total land area of the district.
[b] More than 5000 m^2 floor area of sale spaces in the grocery store.

demand even in the peak demand times.

The second additional scenario was a theoretical analysis of a district operated 100% with renewable energy. In the second additional scenario, the district heating was generating thermal energy from wood chips, and the annual amount of electricity demand would be covered fully with PV production and wind turbines. This option required that the city plan would have been radically modified by adjusting the alignment of the buildings to maximise their potential for solar energy utilisation. In this situation, the solar electricity supply surface could have been doubled compared to the above real life option, which meant that all the roof surfaces could be utilised for solar electricity production. This would have required extreme changes in the city plan to enable the mounting of all roof surfaces optimally towards south. In this scenario, 11,200 m^2 of photovoltaic panels could have been installed in the Kivistö area, and 60,000 m^2 of photovoltaic panels in the Eriksnäs area.

6. Analysis results of case areas

Ideal energy solutions for the urban plans of the case areas were studied with the developed Kurke tool using the energy and emission analysis methodology presented in section 4. The district energy analyses included 1) energy demand of buildings and transportation, 2) impacts of improved transport design choices and 3) comparing CO_2 emissions of energy supply options.

6.1. Building energy demands in the case areas

The energy demands of buildings were compared between two scenarios: 1) a typical basic design, and 2) a very energy efficient (EE) design. The typical basic design was the average energy demand of new buildings that have been built according to the current Finnish building regulations (year 2012 level), and the EE scenario represents very energy efficient buildings (see Table 2). Fig. 5 shows the effects of improving energy efficiency of buildings. Buildings' heating energy demand could be decreased up to 24% through realistic energy efficiency improvements. However, reducing the electricity demand via the urban plans seemed to be more challenging (only 3% in the studied cases). Due to the high areal density of the Kivistö area, the share of district heating losses was relatively small (only 3% of the total heat demand). In contrast to the Kivistö case, the share of heat distribution losses in the Eriksnäs case was 8% due to lower areal density. The whole energy demand of the case areas in basic and very energy efficient designs have been listed in Table 9.

6.2. Low carbon transportation planning in case areas

The average daily passenger kilometres in business-as-usual planning have been shown for both case areas in Table 10. The share of the use of the private cars in the passenger kilometres was on average 66% in case 1 Kivistö and 71% in case 2 Eriksnäs. Passengers in Eriknäs also

Table 8
The boundaries and potentials for energy supply alternatives.

Energy supply alternatives	Case 1: Kivistö	Case 2: Eriksnäs
Total roof surface area	11,200 m^2	60,000 m^2
Maximum roof surface available for PV panels (50% of the total area)	5600 m^2	30,000 m^2
Maximum heat demand for solar collectors heat supply (50% of hot domestic water heating demand in buildings for during March-October)	2005 MWh/a	11,730 MWh/a
Small scale wind energy capacity	1 MW	3 MW
- produced with small vertical axis wind turbines	5 turbines	15 turbines
Additional scenario 1: district level heat pump	90% from heat pump and 10% from electrical heating	90% from heat pump and 10% from electrical heating
Additional scenario 2: 100% renewable energy: district heating from wood boiler, PVs for all roof surfaces, and rest of the electricity demand with wind energy	11,200 m^2 PV (26% of electricity demand), 74% from wind	60,000 m^2 of PV (20% of electricity demand), 80% from wind

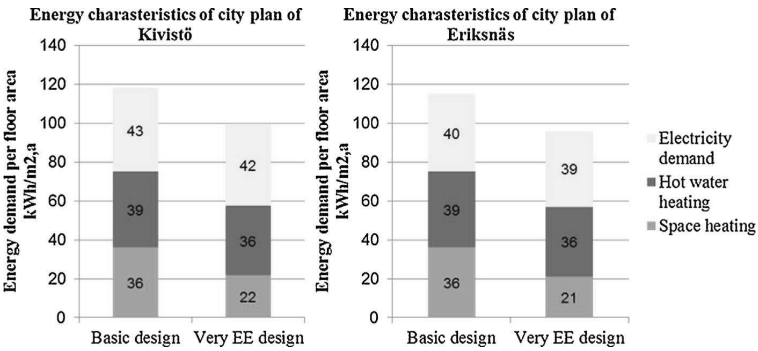


Fig. 5. Building energy demands of case areas (Kivistö in the left and Eriksnäs in the right) in the basic and the very energy efficient building design scenarios.

Table 9
Energy demand for the whole area in basic and very energy efficient design.

Building energy demand in case areas [MWh/a]	Case 1: Kivistö		Case 2: Eriksnäs	
	basic	EE	basic	EE
Total electricity demand	4830	4696	33,945	33,111
Space heating	4036	2432	25,749	18,114
Hot domestic water heating	4424	4012	33,003	29,990
Distribution losses from district heating	254	193	5228	4281
Total heat demand	8714	6637	63,981	52,385

Table 10
Average passenger kilometres per person per day with business-as-usual transport system design.

Modal spit	Passenger kilometres per person per day	
	Case 1: Kivistö	Case 2: Eriksnäs
Private cars	25.0	28.9
City bus (diesel)	3.5	3.5
City bus (gas)	0.0	0.0
Local train (electricity)	3.9	2.8
Pedestrian	1.3	1.1
Bicycling	0.7	0.7
The underground/tram	0.6	0.5
Other (plane, ship, etc.)	2.7	3.5
Total	37.6	40.9

had longer daily transportation distances than in Kivistö. The difference between cases was caused by the density of the areas and the average distances to daily services.

The urban planning choices that make alternative, more sustainable and low carbon transport modes more favourable have been listed in Table 11, with their estimated potential impacts compared to business-as-usual transportation system design. The potential improvements in transportation system design in both case areas were recognised with the aim to support people to increase walking and bicycling and using public transportation, and hence reducing the need for private cars.

If transportation infrastructure was planned to support alternative, more sustainable mobility choices, the share of private cars could have been reduced with sustainable planning choices in the Kivistö area from 66% to 44% and in Eriksnäs from 71% to 59% (Fig. 6).

The CO_2 emissions were calculated for both areas to compare BAU and improved planning scenarios. As a result of more sustainable transport planning choices, Fig. 7 shows the estimated annual CO_2 equivalent emission reduction potentials of 21% in the Kivistö urban plan and 11% in the Eriksnäs urban plan. This CO_2 emission reduction potential was significant, as 470 tCO_2/a per resident in Kivistö and 120 tCO_2/a per resident in Eriksnäs could have been saved on average due to low carbon urban planning choices. In total, this would mean annually total CO_2 emission savings of 976,000 tCO_2/a in Kivistö and 2022 000 tCO_2/a in Eriksnäs.

6.3. *Energy supply alternatives*

Local energy supply alternatives were evaluated and their CO_2 equivalent emissions were compared in the case areas. The requirements, boundaries, and input data used in the calculations have been described in Section 5.2.

In Kivistö, the maximum potential for solar electricity yield was 616 MWh/a, supplying 13% of the required electricity demand in the area. In the Eriksnäs case, the maximum solar electricity yield was 3000 MWh/a, which was 10% of the total electricity demand.

As a result, the maximum solar collector area, which would not require any additional energy storage or heat distribution outside of the area in the summertime, was calculated to be 5130 m^2 of solar collectors in the Case 1 Kivistö. These collectors would require 46% of the planned total roof area. In the Eriksnäs case area, the maximum potential area for solar thermal collectors was 30,000 m^2, which is 50% of the total roof area. The annual wind energy supply would have been approximately 1000 MWh/a in Kivistö and 3000 MWh/a in Eriksnäs.

The second additional scenario studied a what-if case for supplying 100% renewable energy for the district. In this scenario, 11,200 m^2 of photovoltaic panels could have been installed in the Kivistö area covering up to 26% of the annual electricity demand, and 60,000 m^2 of photovoltaic panels in Eriksnäs, covering 20% of the annual electricity demand. The rest of the annual electricity demand needed to be covered

Table 11
Improved transportation system planning choices compared to business-as-usual, and related impacts to the share of the transportation modal split.

Transportation plans	Case 1: Kivistö	Case 2: Eriksnäs
Separate bicycling roads and bicycle parking facilities	excellent (bicycling + 4%)	good (bicycling + 2%)
Centralized car parking facilities	50% of parking (private cars −2%)	none (private cars ± 0%)
Distance to local train station in the area	less than 400 m (local trains + 4%)	400–600 m (local trains + 2%)
Distance to local services (grocery shop, day care, elementary school)	all within 400 m (walking and bicycling + 4%)	all within 400 m (walking and bicycling + 4%)
Frequent and high-quality bus and tram connections	excellent (public transport + 4%)	good (public transport + 2%)
Dense and safe walking routes with high quality design	excellent (walking + 4%)	good (walking + 2%)

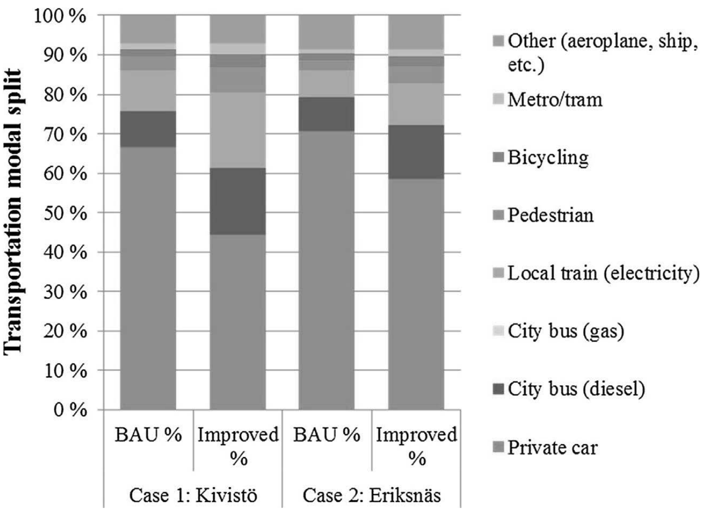


Fig. 6. Comparison of transportation modal splits in business-as-usual and with improved planning choices in the Kivistö and Eriksnäs areas.

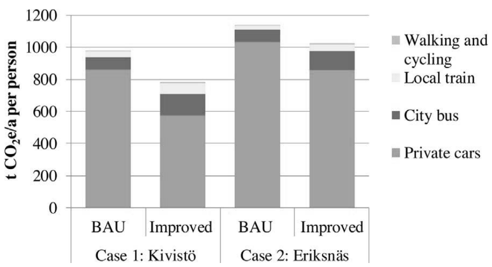


Fig. 7. Annual CO_2 equivalent emissions per person from transportation in the Kivistö and Eriksnäs areas.

with other sources, meaning additional supply of 74% (3475 MWh/a) of the total electricity demand of Kivistö and 80% (26,489 MWh/a) in Eriksnäs. As an example, the rest of the electricity yield was covered with wind energy, requiring 3.8 MW of capacity from a wind mill park for Kivistö and 28 MW of capacity for Eriksnäs.

6.4. The CO_2 equivalent emissions in case areas

The energy supply alternatives and their CO_2 equivalent emissions have been shown in Fig. 8 for the Kivistö case and Fig. 9 for the Eriksnäs case. These figures showed that typical Finnish heating energy solutions (district heating and electric heating) caused on average the highest emission rates when compared to potential renewable energy options. These district heating emission rates represented the average national emission level, but in reality emissions from each district heating plant varies locally based on used fuel. This can also be seen from Figs. 8 and 9, when comparing basic district heating and wood chip based district heating. According to Figs. 8 and 9, it seemed that a large share of distributed energy production would have been required before reducing CO_2 emission significantly. These emission analysis results showed that the smallest amounts of CO_2 equivalent emissions were caused by wood chip based district heating combined with solar heat (case 1: 13 $kgCO_2/m^2$,a and case 2: 11 $kgCO_2/m^2$,a), individual pellet boilers in buildings (case 1: 13 $kgCO_2/m^2$,a and case 2: 12 $kgCO_2/m^2$,a), wood chip based district heating (case 1: 14 $kgCO_2/m^2$,a and case 2: 13 $kgCO_2/m^2$,a) or heat pumps in buildings (case 1: 19 $kgCO_2/m^2$,a and case 2: 18 $kgCO_2/m^2$,a). These figures show that relatively the best options are the same for both cases, even though there are small quantitative differences in the results, which can be seen also from Table 12. In Kivistö, the share of public service buildings and office buildings is 16%, while in Eriksnäs the share is 11%. Since the electricity consumption of these buildings is larger than that of residential buildings, the CO_2 emissions of the electricity demand are larger as well.

In the Kivistö case, improving of buildings' energy efficiency reduced heating related CO_2 emissions by 24% and electricity related emissions by 3%. For Eriksnäs case, the corresponding figures were 18% and 5%. The impact of choosing the energy source was compared to the average CO_2 emissions of Finnish district heating and electricity (in the basic district design case), and the results of this comparison for the CO_2 emission reduction potentials for electricity and heating supply are shown in Table 12.

The CO_2 emissions of alternative urban energy plans have been summarised in Fig. 10 for the Kivistö case, including the comparison of basic and energy efficient buildings, transportation planning choices, and using of different energy sources. Through extreme low carbon planning choices with 100% renewable energy supply, the total CO_2 emissions could have been reduced up to 49%. When compared to the basic design choices that used the average district heating as energy supply, the total CO_2 emission reduction potential of urban planning choices in Kivistö case varied from − 4% with average district heating to − 29% with pellet boilers or district heating with wood chips and solar collectors (Fig. 10).

Total CO_2 equivalent saving potential in Eriksnäs was similar to Kivistö case. The summary of the CO_2 equivalent savings potential has been presented in Fig. 11. In Eriksnäs, the maximum saving was calculated to be 47% by maximizing the share of renewable energy in the local energy system.

6.5. Testing the kurke tool with urban planners

During the tool development process, Kurke tool was discussed and collaboratively tested with the urban planners participating to the project. When urban planners were drafting the design alternatives for the urban plans, they used Kurke tool to check the impacts to the transport modal split and the related environmental impacts. For example, they had used the Kurke tool to check the effect of the density of the district and how the amount of the daily used services affects to the transportation demand and related CO_2 emissions.

Involved urban planners commented that Kurke tool could help

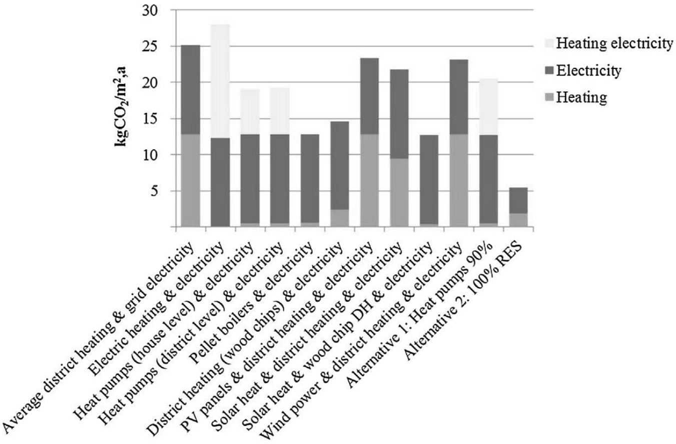


Fig. 8. CO_2 equivalent emissions per floor square meter in the very energy efficient scenario from different energy supply options for the Kivistö case.

them to see the impacts of the urban planning options. The Kurke tool visualises the analysis results in graphs, and urban planners liked the idea that they could use these graphs when communicating the impacts of different design alternatives to decision makers and other stakeholders. For example, the graphs were used both in the presentations of the urban plan drafts as well as in the official report describing the master plan of the Eriksnäs area case.

The Kurke tool has been adopted to support city planning already in some Finnish municipalities. Urban planners, who have been testing the tool in practise, told that it was helpful, and especially they favoured the assessment of the effects of urban planning choices on the passenger transportation. They told that it has proven to be highly useful when drafting urban plans. Urban planners also gave positive feedback about the adequate level of complexity for the tool and the visualisation of results. It seemed that the tool has also managed to raise interest to study alternative potential energy sources to business-as-usual energy supply solutions.

7. Discussion

The developed methodology and the Kurke tool provide urban planners a practical and fast way to assess the energy demand and CO_2 emissions of different urban plan options. While most of existing tools focus on validating the energy efficiency and/or sustainability level

Table 12
Comparison of CO_2 emission reduction potentials (compared to the basic case: average Finnish district heating and electricity supply).

Energy supply option	CO_2 emission reduction potential	
	Case 1: Kivistö	Case 2: Eriksnäs
Heat pumps (producing 100% of the heat)	−16%	−15%
Heat pumps (producing 90% of the heat)	−13%	−9%
District heating using bio based fuels (wood chips or pellets)	−29%	−26%
Electricity from PV panels covering 50% of the roof area	−4%	−1%
District heating with solar collectors (covering 50% of the roof area)	−7%	−5%
Adding 0.5 kW of wind power per resident (in total 1 MW in case 1 and 3 MW in case 2)	−4%	−2%
Theoretical test: 100% of renewable energy from heating with wood, and electricity from PV (maximised production potential) and wind	−49%	−43%
Electrical heating	+8%	+5%

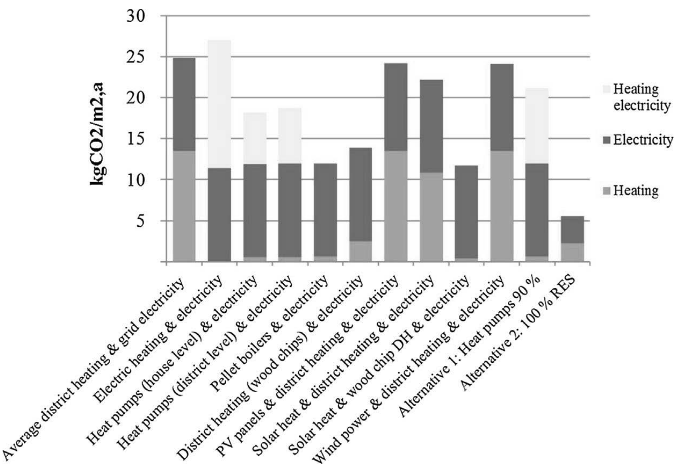


Fig. 9. CO_2 equivalent emissions per floor square meter in the very energy efficient scenario from different energy supply options for the Eriksnäs case.

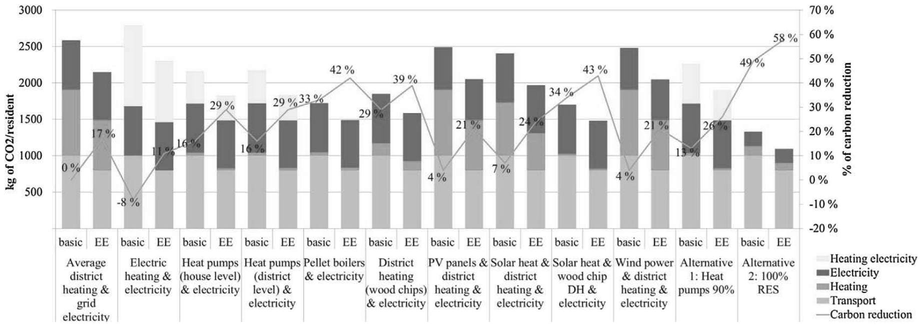


Fig. 10. The CO_2 equivalent emissions per resident in the Kivistö case, with the comparison of basic and energy efficient design alternatives for buildings and transportation, and with using different energy sources.

after for a finalised project, the developed Kurke tool can be used during developing the urban plans. Speciality of the Kurke tool is that it takes into account both energy demand of buildings and transportation, and is developed based on Finnish urban planning context. Kurke tool aims to show and compare alternative renewable energy based energy systems as a valid option for traditional energy sources in districts. This can raise interest towards renewable energy in the discussions and planning decisions among the local authorities.

One of the core advances compared to other existing tools is that the Kurke tool is localised to Finland by following the local urban planning process and including statistical data for Finnish transport and building energy performance. Also, the use of the local language in the tool was considered important. Most of the tools presented in Table 1 are aimed for assessing the final result of the development, such as BREAAM-Community, LEED-ND and CASBEE-UD. SBTool2012 enables setting local prioritisation, but it is more complicated to begin with than BREAAM, CASBEE and LEED (Charoenkit & Kumar, 2014). GBI for Township and Yamagata & Seya's (2013) integrated land use-transport-energy model for future smart cities have been developed for very different operation environment. Finnish Ekotaajama (Hedman et al., 2014) and Amado's et al. (2016) model do not include transportation planning. Cormio's et al. (2003) and (Mourmouris & Potolias, 2013) models are focusing on regional level, not district level planning.

In the proposed methodology, energy demand and emissions were estimated per total area, per person and per floor area. The best suitable reference unit depends on the targeted user and audience group, and it has a significant effect to the final interpretation of the results. While energy demand and emissions per area are interesting for municipalities and energy utilities, they do not support comparisons among different areas. For comparison purposes, units per person and/or per floor area seem to be more suitable. However, these have a difference as well. In general discussion, values per person can be more easily understandable, and they emphasize people's perspectives better. However, it can be unclear what this person is: are they a resident, user, worker, and/or visitor to the area. Values communicated per person are typically a suitable unit when communicating results to end users, while units related to floor area are traditionally used widely in the built environment.

It is also significant whether the communicated values are visualised in energy units (KWh), or in other performance indicators. The described analysis methodology included energy and CO_2 equivalent emissions. However, it would be useful to include in the analysis also the calculation of economic impacts, which tend to engender the interest also among those people that are not interested in energy efficiency or environmental issues. The challenge of economic analysis is to get accurate and up-to-date economic data, which tends to keep changing also case-by-case.

Due to the urban planners' need for fast and practical assessment tools, the methodology presented focused on the annual energy analysis of district plans. However, in practise the energy demand of buildings varies a lot seasonally, but also daily, hourly and during shorter time periods. This was excluded from the analysis method, since the purpose was to support energy and emission awareness of urban planners and to show the magnitude of the required energy supply systems. The methodology assumed that energy demand can be balanced with an external electricity grid, and potentially also with an external district heating network. The more detailed planning and design of district energy systems and their management must be done separately later during the design process, as the proposed evaluation method does not take into account short time energy balancing. Optimal energy management systems are studied recently and various different methods and tools have been developed (Marzband, Alavi, Ghazimirsaeid,

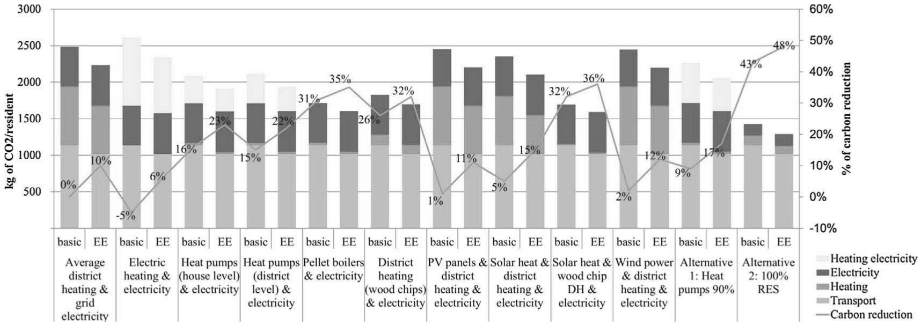


Fig. 11. The CO_2 equivalent emissions per resident in the Eriksnäs case, with the comparison of basic and energy efficient design alternatives for buildings and transportation, and with using different energy sources.

Uppal, & Fernando, 2017; Reynolds, Rezgui, & Hippolyte, 2017; Sheikhi, Rayati, & Ranjbar, 2016). The optimisation methods can provide planners new quantitative insights regarding many trade-offs to inform the urban planning, even though it still seems that optimising of the whole city remains a fallacy (Cajot et al., 2017).

One potential error source in the analysis methodology is the estimation of heat losses in the district heating network. Losses were estimated based on the areal density and average district heating losses in Finland. In practise, these can vary due to different district heating system designs. However, the proposed methodology gives more precise results than by using a single average percentage value for district heating losses. This choice was justified because the target was to produce a practical and easy-to-use evaluation methodology for urban planners, who typically do not have a deep knowledge of energy systems and how to improve the overall energy efficiency.

Urban plan can, and often will, define the main heating energy sources used, at least whether district heating and/or other energy sources will be used in the area. Energy supply decisions are usually done in collaboration with the local energy supplier, city representatives and urban planners. Typically, Finnish urban plans do not set strict requirements for energy supply or energy efficiency, but they can guide and recommend to choosing more sustainable energy sources. The final choices are done by building owners and local energy suppliers. The important issue for the urban planning is to create favourable circumstances for local, sustainable urban energy choices. In practise this can mean e.g. aligning roofs in the urban plan towards south to maximise the potential for solar energy supply. Such suggestions and improved guidance could be embedded to the Kurke tool in the future to increasingly highlight the important role of renewable energy sources in district energy systems and increasingly raise them to the discussion when drafting urban plans and making related decisions. Additional development point for the developed methodology and Kurke tool could be to interconnect it with the models for energy system design and GIS to monitor the results and processes, as also suggested by Manfren et al. (2011).

This study excluded the evaluation of the costs of the energy efficiency and low carbon improvements, as the main target was to study how the planning of low carbon urban areas could be supported. The costs of improved design are distributed to the city, local energy supplier, and building owners. Often investment costs of these kinds of solutions are higher in the beginning, but then the life cycle costs may be lower.

8. Conclusions

The ultimate research aim was to develop a supporting tool, called Kurke, for Finnish urban planners for the evaluation and understanding of the impacts of urban planning choices on the energy efficiency and CO_2 emissions of urban areas. The Kurke tool, developed based on the methodology presented in this paper, also intended to raise urban planners' and municipal decision makers' awareness of alternatives to the traditional designs and their impacts on CO_2 emissions during urban planning process. In addition, energy companies could also benefit from the tool. One of main aims of the tool development was to show the possibilities for increasing the utilisation of renewable energy sources at districts.

Finnish urban planning experts' needs and expectations were studied regarding the tools for the evaluation of energy efficiency at the district level. The survey confirmed the need for practical assessment tools to support energy efficient and sustainable urban area planning. According to the urban planners' requirements, the methodology was kept as practical and fast-to-use as possible. This required balancing between the level of practicality against the complexity and details, which is one of the novel approaches in this research.

A methodology was developed for analysing the energy performance of urban area plans and comparing the impacts of their energy design alternatives on the carbon emissions. The methodology supported holistic energy analysis of urban plans, including energy demand of buildings and transport, and local energy supply options. The energy demand of buildings and transport can be estimated with the Kurke tool, which uses Finnish statistical data. The tool guides the user to consider alternative renewable energy sources and improve the sustainability of the transportation system design with planning choices that reduce the need for using private cars. The methodology targeted to evaluate and compare the impacts of urban planning choices on the annual energy demand and CO_2 equivalent emissions of urban areas in the early urban planning phase. The methodology and tool were tested by comparing the energy planning choices of two Finnish urban area plans. The given base data is applicable in Finland, but the methodology itself can be localised to other countries, if suitable national base data can be found.

Urban planning choices have significant effect on energy and carbon efficiency from buildings, transportation and energy supply system. It seemed that city planning has better possibilities of reducing heating and cooling energy demand, while electricity demand is more dependent on the user behaviour, and hence, its reduction via city planning means is much more challenging. In the Kivistö case, improving buildings' energy efficiency reduced heating related CO_2 emissions by 24% and electricity related emissions by 3%. The corresponding carbon emission reductions in Eriksnäs were 18% and 2%. The most significant reason for the moderate differences in the figures between the two case districts are the differences in their building stock structures. Significant CO_2 emission reduction potentials were also found from the local transportation planning. Especially, those local urban planning choices that reduced citizens' need to use private cars provided a significant carbon emission reduction potential in Finnish cases. For example, in the Kivistö case, the improved transportation planning reduced 20% of CO_2 emissions from the basic design and in Eriksnäs case 10%. The district energy analysis results showed also that the urban planning choices have a significant impact on the CO_2 emissions. In the Kivistö case area, the total CO_2 reduction potential of urban planning choices varied from −4% to −49% depending on the energy source used. In Eriksnäs, the reduction potential of urban planning choices varies from −1% to as high as −47% if the energy demand of the district would be covered 100% by renewable energy sources.

Acknowledgements

This study was part of Finnish research project called Sustainable energy solutions, implementation and guidance of municipal construction. The project was funded by the Finnish Funding Agency for Innovation (TEKES), City of Espoo, City of Jyväskylä, City of Vantaa, City of Kotka, City of Kerava, Fortum, Turku energia, Helen, YIT, Scancool, the Finnish Heat Pump Association SULPU, Aalto University and VTT Technical Research Centre of Finland Ltd. All are gratefully acknowledged. Writers thank also colleagues Pekka Lahti, Abdul Samad Kazi, Åsa Hedman and Riikka Holopainen.

References

Amado, M., Poggi, F., & Amado, A. R. (2016). Energy efficient city: A model for urban planning. *Sustainable Cities and Society, 26*, 476–485. http://dx.doi.org/10.1016/j.scs.2016.04.011.

BREEAM (2012). *BREEAM Communities. Technical Manual SD202-0.1:2012*.

Bhowmik, C., Bhowmik, S., Ray, A., & Pandey, K. M. (2017). Optimal green energy planning for sustainable development: A review. *Renewable and Sustainable Energy Reviews, 71*, 796–813. http://dx.doi.org/10.1016/j.rser.2016.12.105.

Brandoni, C., & Polonara, F. (2012). The role of municipal energy planning in the regional energy-planning process. *Energy, 48*(1), 323–338. http://dx.doi.org/10.1016/j.energy.2012.06.061.

Cajot, S., Peter, M., Bahu, J.-M., Guignet, F., Koch, A., & Maréchal, F. (2017). Obstacles in energy planning at the urban scale. *Sustainable Cities and Society, 30*, 223–236. http://dx.doi.org/10.1016/j.scs.2017.02.003.

Charoenkit, S., & Kumar, S. (2014). *Environmental sustainability assessment tools for low carbon and climate resilient low income housing settlements. Renewable and sustainable*

energy reviews. Elsevierhttp://dx.doi.org/10.1016/j.rser.2014.06.012.
Cormio, C., Dicorato, M., Minoia, A., & Trovato, M. (2003). A regional energy planning methodology including renewable energy sources and environmental constraints. *Renewable and Sustainable Energy Reviews, 7*(2), 99–130. http://dx.doi.org/10.1016/S1364-0321(03)00004-2.
Daseking, W. (2009). *Energy efficiency in built environment: freiburg − A green city − A model for sustainable building. Webcast from sitra Low2No seminar energy efficiency in built environment, 31th of March 2009.* Youtube.
Eicker, U., Monien, D., Duminil, É., & Nouvel, R. (2015). Energy performance assessment in urban planning competitions. *Applied Energy, 155*, 323–333. http://dx.doi.org/10.1016/j.apenergy.2015.05.094.
Energiateollisuus Ry (2015). *Technical quality of district heating and cooling. Kaukolämmön ja –jäähdytyksen tekninen laatu.* Raportti KK5/2015.
European Commission (2011). *Energy roadmap 2050*.
European Commission (2016). *An EU strategy on heating and cooling*.
FINLEX (1999). *Maankäyttö- ja rakennuslaki 132/1999.* [Retrieved from] www.finlex.fi.
FINLEX (2013). *Finnish national energy and climate strategy.* [March].
Finnish Meteorological Institute (2009). *Finnish wind atlas – web tool*.
Finnish national passenger transport survey (2012). *Henkilöliikennetutkimus 2010–2011. Suomalaisten liikkuminen (National passenger travel survey 2010–2011. In Finnish)*.
Gabillet, P. (2015). Energy supply and urban planning projects: analysing tensions around district heating provision in a French eco-district. *Energy Policy, 78*, 189–197. http://dx.doi.org/10.1016/j.enpol.2014.11.006.
Haapio, A. (2012). Towards sustainable urban communities. *Environmental Impact Assessment Review, 32*(1), 165–169. http://dx.doi.org/10.1016/j.eiar.2011.08.002.
Hedman, Å., Sepponen, M., & Virtanen, M. (2014). Energy efficiency rating of districts, case Finland. *Energy Policy, 65*, 408–418. http://dx.doi.org/10.1016/j.enpol.2013.10.022.
Institute for Building Environment and Energy Conservation (IBEC) (2014). *CASBEE for urban development. Comprehensive assessment system for built environment efficiency. Technical manual (2014 edition)*.
International Institute for Sustainability Analysis and Strategy (IINAS) (2016). *GEMIS − global emissions model for integrated systems. Database and software*.
Kılkıs, S. (2014). Energy system analysis of a pilot net-zero exergy district. *Energy Conversion and Management, 87*, 1077–1092. http://dx.doi.org/10.1016/j.enconman.2014.05.014.
Keto, M. (2010). *Energy efficiency indicators of power and heat generation in Finland.* Aalto University.
Lahti, P., Sepponen, M., & Virtanen, M. (2012). *Kunnallisten rakennushankkeiden kestävät energiaratkaisut aluenäkökulmasta.* [Espoo. Retrieved from] http://energytech.aalto.fi/fi/research/energy_efficiency_and_systems/heating_ventilating_and_air_conditioning/kurke_loppuraportti_vtt_30_11_2012.pdf.
Leal, V. M. S., & Azevedo, I. (2016). Setting targets for local energy planning: Critical assessment and a new approach. *Sustainable Cities and Society, 26*, 421–428. http://dx.doi.org/10.1016/j.scs.2016.04.010.
Loiseau, E., Junqua, G., Roux, P., & Bellon-Maurel, V. (2012). Environmental assessment of a territory: An overview of existing tools and methods. *Journal of Environmental Management, 112*, 213–225. http://dx.doi.org/10.1016/j.jenvman.2012.07.024.
Manfren, M., Caputo, P., & Costa, G. (2011). Paradigm shift in urban energy systems through distributed generation: methods and models. *Applied Energy, 88*(4), 1032–1048. http://dx.doi.org/10.1016/j.apenergy.2010.10.018.
Martikainen, R. (2013). *Kaukolämpöverkon verkostohyötysuhteen parantaminen. In Finnish. (Improving the network efficiency in a district heating network.).* Tampere University of Technology. [Retrieved from] https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/21757/Martikainen.pdf.
Marzband, M., Alavi, H., Ghazimirsaeid, S. S., Uppal, H., & Fernando, T. (2017). Optimal energy management system based on stochastic approach for a home Microgrid with integrated responsive load demand and energy storage. *Sustainable Cities and Society, 28*, 256–264. http://dx.doi.org/10.1016/j.scs.2016.09.017.
Mickwitz, P., Hilden, M., Seppälä, J., & Melanen, M. (2011). Sustainability through system transformation: Lessons from Finnish efforts. *Journal of Cleaner Production, 19*(16), 1779–1787. http://dx.doi.org/10.1016/j.jclepro.2011.07.011.
Ministry of Economic Affairs and Employment (2017). *Government report on the national energy and climate strategy for 2030*. [Retrieved from] http://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/79189/TEMjul_4_2017_verkkojulkaisu.pdf.
Ministry of Economic Affairs and Employment (2012a). *D3 (2012) Energy efficiency of buildings, regulations and guidelines.* [Retrieved from] http://www.finlex.fi/data/normit/37188-D3-2012_Suomi.pdf.
Ministry of Economic Affairs and Employment (2012b). *D5 (2012) Calculation of power and energy needs for heating of buildings, guidelines.* National Building Code of Finland, Energy Efficiency. [Retrieved from] http://www.ym.fi/download/noname/%7B8C5C3B41-E127-4889-95B0-285E9223DEE6%7D/40468.
Monni, S., & Syri, S. (2011). Weekly greenhouse gas emissions of municipalities: Methods and comparisons. *Energy Policy, 39*(9), 4755–4765. http://dx.doi.org/10.1016/j.enpol.2011.06.051.
Mourmouris, J. C., & Potolias, C. (2013). A multi-criteria methodology for energy planning and developing renewable energy sources at a regional level: A case study Thassos, Greece. *Energy Policy, 52*, 522–530. http://dx.doi.org/10.1016/j.enpol.2012.09.074.
Municipality of Vantaa (2012). *Marja-Vantaa city plan. Draft city plan under planning*.
Neenan, B., & Hemphill, R. C. (2008). Societal benefits of smart metering investments. *Electricity Journal, 21*(8), 32–45. http://dx.doi.org/10.1016/j.tej.2008.09.003.
Neves, A. R., & Leal, V. (2010). Energy sustainability indicators for local energy planning: Review of current practices and derivation of a new framework. *Renewable and Sustainable Energy Reviews, 14*(9), 2723–2735. http://dx.doi.org/10.1016/j.rser.2010.07.067.
Nystedt, Å., Sepponen, M., & Virtanen, M. (2012). *Design principles for rural eco districts. Ekotaajaman suunniteluperiaatteet.* [Espoo. Retrieved from] http://www.vtt.fi/inf/pdf/technology/2012/T24.pdf.
Official Journal of the European Union (2010). Directive 2010/31/EU of the European Parlament and of the Council of 19 May 2010 on the energy performance of buildings (recast). *Official Journal of the European Union,* 13–35.
Ouhajjou, N., Loibl, W., Fenz, S., & Tjoa, A. M. (2017). Stakeholder-oriented energy planning support in cities. *Sustainable Cities and Society, 28*, 482–492. http://dx.doi.org/10.1016/j.scs.2016.08.006.
Paiho, S., Palos, S., Airaksinen, M., Ala-Juusela, M., Guangyu, C., Heimonen, I., et al. (2013). *Eco-efficient solutions for China's urbanization – Guidebook.* [Retrieved from] http://www.vtt.fi/inf/pdf/technology/2013/T105.pdf.
Pina, A., Silva, C., & Ferrão, P. (2012). The impact of demand side management strategies in the penetration of renewable electricity. *Energy, 41*(1), 128–137. http://dx.doi.org/10.1016/j.energy.2011.06.013.
Poggi, F., Firmino, A., & Amado, M. (2017). Assessing energy performances: A step toward energy efficiency at the municipal level. *Sustainable Cities and Society, 33*, 57–69. http://dx.doi.org/10.1016/j.scs.2017.05.014.
Reynolds, J., Rezgui, Y., & Hippolyte, J.-L. (2017). Upscaling energy control from building to districts: Current limitations and future perspectives. *Sustainable Cities and Society*. http://dx.doi.org/10.1016/j.scs.2017.05.012.
Sameti, M., & Haghighat, F. (2017). Optimization approaches in district heating and cooling thermal network. *Energy and Buildings, 140*, 121–130. http://dx.doi.org/10.1016/j.enbuild.2017.01.062.
Sepponen, M., Virtanen, M., & Lahti, P. (2012). *Kurke alue-energia-analyysityökalu.* Espoo, Finland: VTT and Aalto University. [Retrieved from] http://energytech.aalto.fi/fi/research/energy_efficiency_and_systems/heating_ventilating_and_air_conditioning/kurke_laskentatyokalu_vtt_30_11_2012.zip.
Sheikhi, A., Rayati, M., & Ranjbar, A. M. (2016). Demand side management for a residential customer in multi-energy systems. *Sustainable Cities and Society, 22*, 63–77. http://dx.doi.org/10.1016/j.scs.2016.01.010.
Sperling, K., Hvelplund, F., & Mathiesen, B. V. (2011). Centralisation and decentralisation in strategic municipal energy planning in Denmark. *Energy Policy, 39*(3), 1338–1351. http://dx.doi.org/10.1016/j.enpol.2010.12.006.
Statistics Finland (2015). *Energy supply and consumption.* [On-line databases].
Tuominen, P., Holopainen, R., Eskola, L., Jokisalo, J., & Airaksinen, M. (2014). Calculation method and tool for assessing energy consumption in the building stock. *Building and Environment, 75*, 153–160. http://dx.doi.org/10.1016/j.buildenv.2014.02.001.
US Green Building Council (2009). *LEED 2009 for neighborhood development rating system created by the congress for the new urbanism, natural resources defense green building council (Updated May. Development, (May 2011).* 148.
VTT Lipasto. Online database (2009). *Unit emissions of vehicles in Finland*.
Wedding, G. C., & Crawford-Brown, D. (2007). Measuring site-level success in brownfield redevelopments: A focus on sustainability and green building. *Journal of Environmental Management, 85*(2), 483–495. http://dx.doi.org/10.1016/j.jenvman.2006.10.018.
Windside (2016). *WS-4 model information from vertical axis wind turbine manufacturer.* [Retrieved from] http://www.windside.com/products.
Yamagata, Y., & Seya, H. (2013). Simulating a future smart city: An integrated land use-energy model. *Applied Energy, 112*, 1466–1474. http://dx.doi.org/10.1016/j.apenergy.2013.01.061.
Yeo, I. A., Yoon, S. H., & Yee, J. J. (2013). Development of an environment and energy Geographical Information System (E-GIS) construction model to support environmentally friendly urban planning. *Applied Energy, 104*, 723–739. http://dx.doi.org/10.1016/j.apenergy.2012.11.053.
Zanon, B., & Verones, S. (2013). Climate change, urban energy and planning practices: italian experiences of innovation in land management tools. *Land Use Policy, 32*, 343–355. http://dx.doi.org/10.1016/j.landusepol.2012.11.009.

Glossary and abbreviations

Areal efficiency (e_a): Share of the net floor area of all buildings locating in the area compared to the total land area in the city or district plan. calculated as the total net floor area of all buildings divided by the total land area
BAU: Business-as-usual
CHP: Combined heat and power production
DH: District heating
EE: Energy efficient
Mixed-use: Land is used for mixed purposes, e.g. residential, public and private services, office, small industry etc.
Modal split: Percentage of travelled distance using a particular transportation type.
Nearly zero energy buildings: Highly energy efficient buildings that produce significant part of their energy demands from renewable energy sources either on-site or nearby.
PV: Photovoltaic panel
Urban planning: Land use planning

Appendix F: Building parameters for simulations

Table F1. Building parameters for energy demand analysis: U-values, ventilation heat recovery efficiency and air exchange rate (n_{50} value). 2010 building regulations from Ministry of Environment C3 [2010], and low energy and passive level building parameters are estimated by Jari Shemeikka at VTT.

Energy efficiency level of a type building	U-values [W/m²K]				Air exhange	
	External walls	Base floor	Roof	Windows and doors	heat recovery efficiency	air exhange rate
2010 buildings	0,17	0,16	0,09	1	50	0,08
Low energy building	0,12	0,12	0,08	0,8	80	0,04
Passive building	0,08	0,08	0,07	0,7	85	0,024

Table F2. Buildings analysed in Toivakka, in the Saarinen neighbourhood. Parameters are set based on stakeholder interviews of Hannu Mäntyjärvi and Erkki Pyökkimies in the municipality of Toivakka.

Type building	Number of buildings	Total floor area [m2]	Number of floors	Floor height [m]	Shape	X/Y ratio	X:width t of the building [m]	Y: lenght of the building [m]	Residents in the building
Single family house	19	125	1	2.7	retangle	0.5	7.91	15.81	4
Row house (3 apart.)	1	240	1	2.7	retangle	0.4	9.80	24.49	9

Figure F1. Type buildings shape in Toivakka, based on the stakeholder interviews in the city of Toivakka.

Appendix G: Simulated energy demands for type buildings in varying energy efficiency levels

Table G1: Single family home (125 m²) energy demands.

	Space heating demand [kW]	Domestic hot water demand [kW]	Electrical power demand [kW]	Annual electricity use [kWh/a]
2010 building	5	59	11	5 040
Low energy building	3	59	11	4 740
Passive building	2	59	11	4 740

Table G2: Single family home (125 m²) space heating demand at monthly level.

Month	2010 building				Low energy building				Passive building			
	Space heating kWh	Hot dom. water kWh	Heat losses kWh	**Total kWh**	Space heating kWh	Hot dom. water kWh	Heat losses kWh	**Total kWh**	Space heating kWh	Hot dom. water kWh	Heat losses kWh	**Total kWh**
January	1 734	118	18	**1 870**	1 008	118	10	**1 136**	691	118	7	**816**
February	1 529	118	18	**1 665**	846	118	10	**974**	552	118	7	**677**
March	1 101	118	18	**1 237**	570	118	10	**698**	349	118	7	**474**
April	785	118	18	**921**	372	118	10	**500**	221	118	7	**346**
May	259	118	18	**395**	130	118	10	**258**	87	118	7	**212**
June	0	118	18	**136**	0	118	10	**128**	0	118	7	**125**
July	0	118	18	**136**	0	118	10	**128**	0	118	7	**125**
August	0	118	18	**136**	0	118	10	**128**	0	118	7	**125**
September	375	118	18	**511**	172	118	10	**300**	108	118	7	**233**
October	843	118	18	**979**	424	118	10	**552**	257	118	7	**382**
November	1 043	118	18	**1 179**	570	118	10	**698**	365	118	7	**490**
December	1 524	118	18	**1 660**	883	118	10	**1 011**	600	118	7	**725**
Annual heating demand			**total**	**10 825**	**kWh**		**total**	**6 511**	**kWh**		**total**	**4 730 kWh**

Table G3: Row house (total 240 m²) energy demands.

	Space heating demand [kW]	Domestic hot water demand [kW]	Electrical power demand [kW]	Annual electricity use [kWh/a]
2010 building	9	80	36	11 640
Low energy building	6	80	36	10 740
Passive building	5	80	36	10 740

Table G4: Row house (total 240 m²) space heating demand at monthly level.

Month	2010 building				Low energy building				Passive building			
	Space heating kWh	Hot dom. water kWh	Heat losses kWh	**Total kWh**	Space heating kWh	Hot dom. water kWh	Heat losses kWh	**Total kWh**	Space heating kWh	Hot dom. water kWh	Heat losses kWh	**Total kWh**
January	2 791	462	33	**3 286**	1 492	462	21	**1 975**	985	462	17	**1 464**
February	2 418	462	33	**2 913**	1 226	462	21	**1 709**	784	462	17	**1 263**
March	1 656	462	33	**2 151**	790	462	21	**1 273**	493	462	17	**972**
April	1 142	462	33	**1 637**	530	462	21	**1 013**	343	462	17	**822**
May	393	462	33	**888**	221	462	21	**704**	161	462	17	**640**
June	0	462	33	**495**	0	462	21	**483**	0	462	17	**479**
July	0	462	33	**495**	0	462	21	**483**	0	462	17	**479**
August	0	462	33	**495**	0	462	21	**483**	0	462	17	**479**
September	511	462	33	**1 006**	257	462	21	**740**	182	462	17	**661**
October	1 202	462	33	**1 697**	561	462	21	**1 044**	356	462	17	**835**
November	1 529	462	33	**2 024**	747	462	21	**1 230**	470	462	17	**949**
December	2 403	462	33	**2 898**	1 267	462	21	**1 750**	825	462	17	**1 304**
Annual heat	**kWh**		**yht.**	**19 985**	**kWh**		**yht.**	**12 887**	**kWh**		**yht.**	**10 347 kWh**

Aalto-DD 65/2018
VTT SCIENCE 174

Many climate and energy policy frameworks are leading to stricter energy efficiency and emission regulations and growing share of renewable energy. City planners and municipal authorities make design choices and decisions that significantly impact the energy efficiency and emissions of districts. Energy efficient and sustainable districts can be developed through holistic energy planning. Energy efficient urban planning can be supported by analysing the energy performance of districts and comparing the environmental impacts of energy alternatives. A set of business concept elements have been developed in a form of a cookbook, which can be used to create case-specific business models by accounting for local operation environment, conditions and needs. The results can foster and support discussion and raise new ideas for alternative district energy systems.

ISBN 978-952-60-7933-2 (printed)
ISBN 978-952-60-7934-9 (pdf)
ISSN-L 1799-4934
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)

978-951-38-8632-5 (printed)
978-951-38-8631-8 (pdf)
2242-119X
2242-119X (printed)
2242-1203 (pdf)

Aalto University
School of Engineering
Department of Mechanical Engineering
www.aalto.fi

BUSINESS +
ECONOMY

ART +
DESIGN +
ARCHITECTURE

SCIENCE +
TECHNOLOGY

CROSSOVER

DOCTORAL
DISSERTATIONS