Energy technology

Energy-efficient city planning

The role and importance of actionable regulations

Åsa Hedman

Aalto University

DOCTORAL DISSERTATIONS

Aalto University publication series
DOCTORAL DISSERTATIONS 10/2016
VTT SCIENCE 123

Energy-efficient city planning

The role and importance of actionable regulations

Åsa Hedman

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 216, Otakaari 4, at Aalto University, on the 22nd of January 2016 at 12 noon.

Aalto University
School of Engineering
Energy Technology

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

Thesis advisors
Prof. Dr., Abdul Samad (Sami) Kazi
Vice President
VTT Technical Research Centre of Finland Ltd
Finland

Preliminary examiners
Associate Professor. Dr. Natasa Nord
NTNU – Faculty of Engineering Science and Technology
Department of Energy and Process Engineering
Norway

Prof. Dr. Poul Alberg Østergaard
Aalborg University
Department of Development and Planning
Denmark

Opponents
Dr. MSc Arch, Phd. Minna Sunikka/Blank
University of Cambridge
Department of Architecture
United Kingdom

Aalto University publication series
DOCTORAL DISSERTATIONS 10/2016

VTT SCIENCE 123

ISBN 978-952-60-6621-9 (printed)
ISBN 978-952-60-6622-6 (pdf)
ISSN-L 1799-4934
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)
http://urn.fi/URN:ISBN:978-952-60-6622-6

ISBN 978-951-38-8391-1 (printed)
ISBN 978-951-38-8390-4 (pdf)
ISSN-L 2242-119X
ISSN 2242-119X (printed)
ISSN 2242-1203 (pdf)
http://urn.fi/URN:ISBN:978-951-38-8390-4

Unigrafia Oy
Helsinki 2016

Finland

NORDIC ECOLABEL
441 697
Printed matter

Aalto University

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

Abstract

Author
Åsa Hedman

Name of the doctoral dissertation
Energy-efficient city planning - the role and importance of actionable regulations

Publisher School of Engineering

Unit Energy technology

Series Aalto University publication series DOCTORAL DISSERTATIONS 10/2016

Field of research Sustainbale built environment

Manuscript submitted 22 October 2015 **Date of the defence** 22 January 2016

Permission to publish granted (date) 25 September 2015 **Language** English

☐ **Monograph** ☒ **Article dissertation (summary + original articles)**

Abstract
This thesis focuses on energy efficient urban planning and the role of legislation within that context. The objective of this thesis is to analyse if energy efficiency of districts is improved by a regulative approach into planning, if proper tools and guidelines to support the planning are available.

The thesis is based on four journal articles and one conference paper. The thesis examines the advantages of a holistic approach in the planning of energy systems both when building new districts as in renovating old ones. It also examines the importance of supportive tools for city planners and planners of energy systems.

The results of the analysis show that a holistic approach and supportive tools enable more energy efficient solutions. The key to developing sustainable city plans are for different disciplines to work closely together throughout the whole planning process. Such collaboration might require certain regulative measures to become reality since stakeholders will work towards a common goal that might differ from their individual ones. The energy-efficiency of city plans would benefit from a higher degree of regulation by enabling a push of energy efficient solutions to be realised. Solutions and regulations need to be adapted to local contexts.

A regulative approach is beneficial when long term solutions are sought, that doesn't bring short term economic benefits but serve the society well on a longer time perspective. The challenge is to have regulation on a level that both steers the development towards the overall optimised solutions without hindering new innovative solutions to be born.

The thesis gives concrete recommendations for how to improve the regulations in the city planning process to enable a more energy efficient built environment.

Keywords urban planning, energy efficiency, renewable energy

ISBN (printed) 978-952-60-6621-9 **ISBN (pdf)** 978-952-60-6622-6

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

Location of publisher Helsinki **Location of printing** Helsinki **Year** 2016

Pages 166 **urn** http://urn.fi/URN:ISBN:978-952-60-6622-6

A? Aalto-yliopisto

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

Tiivistelmä

Tekijä
Åsa Hedman

Väitöskirjan nimi
Energiatehokas kaupunkisuunnittelu- regulaation rooli ja tärkeys

Julkaisija Insinööritieteiden korkeakoulu

Yksikkö Energy technology

Sarja Aalto University publication series DOCTORAL DISSERTATIONS 10/2016

Tutkimusala Sustainable built environment

Käsikirjoituksen pvm 22.10.2015 **Väitöspäivä** 22.01.2016

Julkaisuluvan myöntämispäivä 25.09.2015 **Kieli** Englanti

☐ **Monografia** ☒ **Yhdistelmäväitöskirja (yhteenveto-osa + erillisartikkelit)**

Tiivistelmä

Tämä väitöskirja fokusoi energiatehokkaaseen kaupunkisuunnitteluun ja lainsäädännön rooliin siinä. Tavoitteena on osoittaa, että tiukempi sääntely lisää alueiden energiatehokkuutta mikäli tarkoituksenmukaiset työkalut ja ohjeistukset ovat käytettävissä kaupunkisuunnittelussa ja energiajärjestelmien suunnittelussa.

Väitöskirja perustuu neljään tieteelliseen artikkeliin sekä yhteen konferenssijulkaisuun. Väitöskirja tutkii energiajärjestelmien holistisen suunnittelun hyödyt sekä uudisrakentamisessa että korjausrakentamisessa. Se tutkii myös tukevien työkalujen tärkeyttä kaupunkisuunnittelussa sekä energiajärjestelmien suunnittelussa.

Analyysien tulokset näyttävät, että holistinen lähestymistapa ja tukevat työkalut mahdollistavat energiatehokkaampia ratkaisuja. Tiivis yhteistyö eri alojen välillä koko suunnitteluprosessin aikana on kestävän kehityksen mukaisten kaavojen kehittämisessä erityisen tärkeää. Tämänkaltaisen yhteistyön luominen saattaa vaatia tietyn asteen sääntelyä toteutuakseen. Sidosryhmillä on usein tavoitteita jotka eriävät yhteisistä tavoitteista. Ratkaisut ja sääntelyt pitää adaptoida paikallisiin olosuhteisiin ollakseen toteutumiskelpoisia.

Lainsäädännöllinen lähestymistapa on hyödyllinen kun etsitään ratkaisuja jotka hyödyttävät yhteiskuntaa pidemmällä aikavälillä johtuen siitä, että ratkaisut eivät välttämättä tuo lyhyellä ajanjaksolla taloudellisia hyötyjä. Haaste on pitää lainsäädäntö tasolla joka ohjaa kehitystä optimaalisiin ratkaisuihin eikä estä uusien innovatiivisten ratkaisujen syntyä.

Väitöskirja antaa konkreettisia suosituksia kaupunkisuunnittelun sääntelyn parantamiseksi jotta rakennettu ympäristö olisi tulevaisuudessa energiatehokkaampi.

Avainsanat Kaupunkisuunnittelu, energiatehokkuus, uusituva energia

ISBN (painettu) 978-952-60-6621-9 **ISBN (pdf)** 978-952-60-6622-6

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

Julkaisupaikka Helsinki **Painopaikka** Helsinki **Vuosi** 2016

Sivumäärä 166 **urn** http://urn.fi/URN:ISBN:978-952-60-6622-6

A! Aalto-universitetet

Sammandrag

Aalto-universitetet, PB 11000, 00076 Aalto www.aalto.fi

Författare
Åsa Hedman

Doktorsavhandlingens titel
Energieffektiv stadsplanering - rollen och betydelsen av reglering

Utgivare Högskolan för ingenjörsvetenskaper

Enhet Energy technology

Seriens namn Aalto University publication series DOCTORAL DISSERTATIONS 10/2016

Forskningsområde Sustainable built environment

Inlämningsdatum för manuskript 22.10.2015 **Datum för disputation** 22.01.2016

Beviljande av publiceringstillstånd (datum) 25.09.2015 **Språk** Engelska

☐ **Monografi** ☒ **Sammanläggningsavhandling (sammandrag plus separata artiklar)**

Sammandrag

Denna avhandling berör energieffektiv stadsplanering och rollen av reglering däri. Målsättningen med avhandlingen är att analysera huruvida energieffektiviteten inom områdesplanering förbättras av en mer reglerad planering som stöds av ändamålsenliga verktyg och riktlinjer.

Avhandlingen består av fyra vetenskapliga journal artiklar och en konferensartikel. Den undersöker fördelarna med att planera energisystemen holistiskt såväl i nya områden som i renovering av existerande områden. Den undersöker också vikten av stödjande verktyg för stadsplanerare och planerare av energisystem.

Resultaten av analyserna visar att ett holistiskt grepp och stödjande verktyg möjliggör mer energieffektiva lösningar. Det viktigaste i utvecklingen av hållbara stadsplaner är att olika discipliner samarbetar genom hela planeringsprocessen. Ett sådant samarbete kan kräva en del regulativa åtgärder för att förvekligas då det gemensamma målet kan vara nåt annat än de individuella målen hos de olika aktörerna. Stadsplaners energieffektivitet kunde förbättras med en högre grad av reglering eftersom det skulle möjliggöra en press på införandet av energieffektiva lösningar. Lösningar och regleringar måste alltid adapteras till det lokala kontextet.

Då man man söker lösningar som på lång sikt stöder samhället men inte hämtar ekonomisk nytta på kort sikt är reglering till nytta. Utmaningen är att reglera på en nivå som styr utvecklingen mot helhets optimerade lösningar utan att hindra att nya innovativa lösningar utvecklas.

Avhandlingen ger konkreta rekommendationer för förbättrandet av regleringen av stadsplaneringsprocessen för att möjliggöra en mer energieffektiv byggd miljö.

Nyckelord Stadplanering, energieffektivitet, förnybar energi

ISBN (tryckt) 978-952-60-6621-9 **ISBN (pdf)** 978-952-60-6622-6

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

Utgivningsort Helsingfors **Tryckort** Helsingfors **År** 2016

Sidantal 166 **urn** http://urn.fi/URN:ISBN:978-952-60-6622-6

Preface

This study is summarising my core research work during the last decade. The topic sustainable communities has been close to my heart for a very long time. Energy issues have been my core competence area but my interest has reached further than that. My work started to move into district level analyses and focusing mostly on the process of the development towards a more sustainable future. The challenge in getting different stakeholders to work towards a common goal fascinates me and sessions with different stakeholders always bring some new thoughts and ideas to me. The fact that we see the world in such different ways is fascinating and should be more taken advantage of.

My four years in local politics in my home town Porvoo gave me valuable insight into the decision making processes in Finnish communities. To experience how decision makers experience the process of city planning was very eye opening to me. This experience gave me lots of valuable understanding that I have been able to utilise in my research work after that, and in summarising this thesis. To take time to work a bit outside your own field of expertise and comfort zone gives you lots of valuable experience and increased holistic knowhow.

Working in international projects in different cultures has also been very valuable to me and has given me an increased understanding about different cultures and what an “EcoCity” means in different places in the world. It has also been very challenging and even frustrating at times, but I feel that I have evolved both as a person as a researcher from all this experience. New contacts and friends in different parts of the world is naturally also very valuable to me.

I wish to express my gratitude to my professor Risto Lahdelma who has been very supporting throughout the process of writing the thesis. He has shown a genuine interest in my work and has given me lots of good advice in the finalisation steps.

Without my mentor and supervisor Abdul Samad (Sami) Kazi, writing this thesis would have been much harder. The best advice I got from him after deciding to work towards a doctoral degree was that “*you don’t have to win the Nobel prise, you need to show that you can do research, which you can, right?, So just do it!”.* Despite his very busy work schedule Sami always had time to discuss the thesis with me, to give comments which were very valuable. His advice about the process of writing has been very helpful to me also in my other research work. Thank you Sami!

I have been lucky to work with the most talented people there is within this field, we have been forming very good teams where ideas are shared openly and we know each other's strengths and weaknesses and share the work according to those. My deepest gratitude goes to my colleagues and co-authors, I would not have done all this work alone, and above all, it would not have been as much fun as it has been with you! Thank you Satu Paiho, Rinat Abdurafikov, Ha Hoang, Mari Hukkalainen, Malin zu Castell-Rüdenhausen, Mikko Virtanen, Jari Shemeikka, Krzysztof Klobut and Ilpo Kouhia who unfortunately is not with us anymore.

Last but not least I must give a huge thank you to my family and especially to my husband Eric. He has shown a real interest in my topic and has been engaged in many discussions about the topic and, being within a different field of expertise, has raised questions that I hadn't thought of before, which improves the quality of the work. Thank you Eric for your support!

Porvoo, 15.10.2015

Table of Contents

List of publications

This thesis is based on the following original publications which are referred to in the text as I–IV (Appendix A). The publications are reproduced with kind permission of the publishers.

I Nystedt, Å., Shemeikka, J. & Klobut, K. 2006. Case analyses of heat trading between buildings connected by a district heating network. Energy Conversion and Management (47), 3652–3658.

II Hedman, Å., Sepponen, M. & Virtanen, M. 2014. Energy efficiency rating of districts, case Finland. Energy Policy (65), 408–418.

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

IV Paiho, S., Hoang, H., Hedman, Å., Abdurafikov, R., Sepponen, M. & Meinander, M. 2014. Energy and emission analyses of renovation scenarios of a Moscow residential district. Energy and Buildings (76), 402–413.

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

Author’s contributions

The author was the main writer in journal Articles I and II and in conference paper V, and co-writer in journal Articles III and IV. The articles were written within projects where the author was either a core team member or a project manager.

Author’s contribution to Article I: The author developed the Excel-based tool with which the analyses were made. The author also did most of the calculations and analyses as well as the actual writing of the paper.

Author’s contribution to Article II: the author was the project manager for the project within which the work was done. She conducted the negotiations with the stakeholders regarding the development of the tool and what analyses were to be made in the different case districts. The tool itself was developed by the co-authors. With the exception of the tool description, most of the article was written by the author.

Author’s contribution to Article III: The work for the article was done as a team effort and the author took part in the whole process of the work. To highlight some specific contribution, the development of the renovation scenarios, summarised in table 3, can be mentioned as well as Chapters 6 and 7 “Non-technical barriers to energy efficiency renovations” and “Discussion”.

Author’s contribution to Article IV: The work for the article was done as a team effort and the author took part in the whole process of the work. To highlight some specific contribution, the development of the district level renovation scenarios, summarised in table 3 can be mentioned. The author was, in addition, the main author of Chapters 5 and 6 Discussions and Conclusions.

Author’s contribution to conference paper V: The author was the project manager for the project within which the work was done. All negotiations with stakeholders were conducted by the author. The questionnaire was developed by the author in cooperation with the co-author. The energy and emission analyses of the case districts were performed by the co-author. The definition of what was to be analysed in the cases was carried out in close cooperation between the author and the co-author.

Terminology list

CHP	Combined Heat and Power
CO_2 equivalent	Shows the effect on global warming of a given type and amount of green-house gases, comparing it with the functionally equivalent amount or con-centration of carbon dioxide (CO_2). The reference GWP, that is, global warming potential is calculated with the use of coefficients
COP	COP or coefficient of performance: the heat coefficient or coefficient of conversion reflecting the efficiency of heat pumps. For instance, a heat pump whose COP equals 3 produces 3 kilo-watts of heat energy using 1 kilowatt of electricity.
Detailed city plan	A detailed plan includes a map where the boundaries are shown for the planned areas. The map also contains information about what purposes differ-ent areas are going to be used for, the level of construction and principles re-garding the localization and size of the building, and also the method of con-struction when needed.
Electrical base load strategy	Micro-CHP plant is designed to supply the minimum amount of power required by the facility. Therefore, the micro-CHP plant can operate at peak power output continuously.
Electrical load tracking strategy	Calls for micro-CHP plant to have an electrical capacity that exceeds the minimum electrical requirement for the facility. The micro-CHP plant output power changes in response to the needs of the facility.
Micro-CHP	Small scale CHP, production capacity less than 100 kW.
SO_2 equivalent	Describes the quantities or concentra-tions of emissions causing acidulation. This is based on the relative acidity of

	SO_2 and is referred to SO_2, NOx, HCl, HF, NH_3 and H_2S emissions.
Thermal base load strategy	The CHP-system is designed to meet the minimum thermal load. Thermal energy to meet peak loads is provided by an auxiliary heat source, such as a boiler. Electrical power is purchased from or sold to the grid to balance the electrical demand for the facility with the power supplied by the fuel cell system.
Thermal load tracking strategy	The CHP-system is designed to follow the thermal load of the facility. Power that is generated during the course of supplying the thermal load is used by the facility to replace purchased electric power. The excess power can often be sold to the utility.
TOPP equivalent	is referred to the mass equivalent of ozone generated from its prophase. TOPP reflects the generation in the troposphere of O_3 ozone that, in summertime, may, for instance, cause smog. The equivalent is calculated according to the relative degree of ozone generation due to CO-, NMVOC-, NOx- and CH4 -emissions. The higher the TOPP equivalent, the greater the probability of summer smog). (GEMIS Manual.)
U-value	A U value is a measure of heat loss in a building element such as a wall, floor or roof. It can also be referred to as an 'overall heat transfer co-efficient' and measures how well parts of a building transfer heat.
WinEtana	Software developed at VTT, for simulating energy demand in buildings.

1. Introduction

The world is facing an enormous challenge in fighting global warming and the depletion of many natural resources. In the developed part of the world, the striving towards a higher quality of life most often takes the shape of consuming more goods and services that use natural resources in one way or the other. In the developing countries, the challenge in terms of sustainability is even greater when the raising of the quality of life to the same level as in the developed world would mean a huge increase in emissions and resource usage.

Urbanisation is a global megatrend that is partly caused by the striving for a higher quality of life. By 2030 more than two-thirds of the world's inhabitants will live in urban areas (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2007). In an increasingly urbanised world, urban planning will play a key role in the sustainability challenge.

Due to increased urbanisation, the role of the built environment in the sustainability challenge will become even greater. Without major changes in the way we build and plan our communities, sustainability will not be increased enough. City planning plays a key role in this development. How our cities and districts are planned affects how they are built and operated. If done wisely, city planning can, have a positive effect on people’s energy consumption behaviour throughout the whole life cycle of the district. This, however, requires a society where the city plans, codes and regulations are implemented and enforced as planned. In many developing countries this is not the case today, often due to corruption (Sundström, 2015). Corruption is most common in the developing countries (Dreher et al., 2007).

The building 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 potential for greenhouse gas reduction is available in buildings (IPCC, 2007). Concerning Finland, it has been estimated that a few percent higher investment in energy-efficient construction and renovation can cut the total primary energy consumption of the country by 4–5% by 2020 and by 5–7% by 2050 (Tuominen et al., 2013).

There are many technologies developed to cut energy use in cities, to improve the transportation solutions, to handle water and waste management in a sustainable way and to increase people's awareness of their energy use. However, there seem to be barriers in taking these solutions into use more widely (Eleftheriadis & Anagnostopoulou, 2015) In many cases the barriers are economic, but there are also other barriers such as a lack of knowhow or lack of supportive governmental policies that can be hindering the usage of sustainable solutions (Zyadin et al., 2014). Regulations have been shown to enable a development towards higher energy-efficiency, the Energy Performance of Buildings Directive 2002/91/EC (EPBD) being a good example of regulations pushing the industry to create more energy-efficient solutions for the market (European Parliament, 2002).

Lately, in Finland, there have been complex projects where all the various characteristics of a district have been considered at the very initial stages of planning (Rajala et al., 2010). In those projects, the results in terms of energy efficiency have been good, but the process has been project-based and has required a great deal of extra resources. The Skaftkärr project in Porvoo, Finland is one good example. The project is described in Rajala et al. (2010). The lessons learnt have so far not been taken into the normal planning procedures. (Rajala et al., 2010, Hedman et al., 2014.)

Urban planning involves a large number of different aspects, and its success greatly depends on the expertise available in the planning phase and on how well local conditions are taken into account. At this time, in Finland, many projects aiming at making city development more eco-efficient are underway (Rajala et al., 2011, Hedman et al., 2014). The hard part here is developing approaches and methods that, while being universally applicable, also allow for the specifics of particular regions/districts to be taken well into account.

Is the energy efficiency of districts supported by a high degree of regulation in the city planning process? Should individual builders have the right to build what they want on their own plot, or should society place heavy constraints on what can and should be built? If so, how can we ensure that the constraints and regulations set are in fact leading to a more energy-efficient and sustainable solution?

This thesis analyses if energy efficiency of districts is improved by a regulative approach to planning, when the proper tools and guidelines are available to support the planning.

The thesis is based on four journal articles and one conference paper summarized below and found at the end of this thesis.

> Article I "Case analyses of heat trading between buildings connected by a district heating network" focuses on district heating sys-

tems. The focus of the article is the concept of heat trading, meaning that buildings are selling excess heat into the district heating system. The study has been done by creating a tool that analyses heat and electricity demand and production in a case district in western Finland. Different operational strategies of micro CHP units were chosen, and the impact on the whole district level heating system was analysed. The possibility to trade heat can be a way to self-sufficiency which, if choices are made wisely, can lead to higher sustainability.

Article II “Energy efficiency rating of districts, case Finland” describes a city planning tool that was developed in order to assess energy efficiency of detailed city plans. The article shows that, by giving the city planners an easy to use tool, the choices made within the detailed city planning phase can lead to higher energy efficiency. Five different case districts in Finland were analysed. Local stakeholders were also involved in the development process of the tool.

Article III “Energy saving potentials of Moscow apartment buildings in residential districts” estimates the energy saving potentials of Moscow apartment buildings through different renovation concepts. Also, the reduction of the district level energy demands resulting from the possible building level energy savings were estimated. The study shows the benefits of performing renovation activities on a district scale with a holistic approach instead of performing actions one-by-one. On a district scale, such actions involve a wide range of stakeholders and also include administrative and other non-technical and non-economical obstacles that require a regulative approach in order to be feasible.

Article IV “Energy and emission analyses of renovation scenarios of a Moscow residential district” analyses different changes made in the energy system of the same case district and their impacts on emissions. Different renewable energy sources were analysed in a case district in Moscow, Russia. The purpose was to assess how low emission values could be achieved by comparing and combining technologies for energy generation, and to clarify which of the combinations presented would be better in terms of produced emissions. The study shows that, through a district level top-down approach, it is easier to affect heat demand than electricity demand. It also discusses the fact that the quality of life is often improved through large renovation activities, which often cannot be performed without a top-down holistic approach due to the economic constraints of individual apartment owners. Emissions analysis shows that it is not that straightforward and simple to analyse the emission impacts of different energy choices. It can be concluded that, in order for a city planner to assess these impacts, supportive tools and guidelines are needed.

Artile V “Development of a concept for ecological city planning for St Petersburg, Russia”. The conference paper describes the work done in the research project, EcoGrad whose aim was to develop a concept for ecological housing areas that would fit in St Petersburg, Russia. A criteria list for ecological residential areas was developed together with local partners. Some differing aspects between Finnish and Russian criteria are pointed out in the paper. Three pilot cases were also studied. A rough plan was made for the pilot areas including placement of buildings and services and transport solutions. Energy systems were modelled and compared, and emissions were calculated. One of the pilot cases is briefly described in the paper. A questionnaire that was distributed to residents who showed a poor willingness to pay for renewable energy and good indoor air quality. Safety issues were highlighted; a majority of the residents does not feel safe in their neighbourhood.

The articles have been done in different research projects briefly described below. A more elaborated description of each project is found in appendix B.

The work in Article I was done within the project Hetra funded by Tekes and VTT. The aim of the project was to develop a concept for heat trading and analyse its potential and impact. The author was taking part in the project as research scientist performing district level energy simulations and creating an Excel based tool for performing simulations of CHP units with different operational strategies. Results from the project are published in the online publication:
http://www.vtt.fi/inf/pdf/tiedotteet/2005/T2305.pdf

The work in Article II was done partly in the project Ekotaajama funded by Sitra, Tekes and the Finnish cities Jyväskylä, Toivakka, Multia, Petäjävesi, Jämsä and Kannonkoski and partly within the Ensio project funded by VTT. The aim of the Ekotaajama project was to develop a district level energy rating classification system and to develop a tool for city planners for assessing the energy efficiency of detailed city plans. In addition several district level energy analyses were done in the 5 case districts comparing different energy solutions for the districts and analysing their impacts on emissions. The author was project manager in the project. Results of the project are published (in Finnish) in the following online publication: http://www.vtt.fi/inf/pdf/technology/2012/T24.pdf

The aim of the Ensio project was to develop a dynamic district level simulation tool based on the APROS tool co-owned by VTT and Fortum Ltd. As part of the project, a Master's thesis was done to which the author of this thesis, Åsa Hedman, was acting as advisor. The aim of the thesis was to analyse how solar energy utilisation could be improved by actions in the city planning process. A web based questionnaire to Finnish city planners was performed which results have been utilised in this thesis.

Articles III and IV were done within the ModernMoscow project funded by the Ministry of Foreign Affairs of Finland. The aim of the project was to prepare a feasibility study for the energy-efficient and sustainable renovation and modernization of a selected district in Moscow, Russia. The author of this thesis was a senior researcher in the project with the main responsibility of creating the district level criteria setting for sustainable renovations. She also took part in the energy analyses and in the development of the business models. Results from the project has been published in the following online publications:
http://www.vtt.fi/inf/pdf/technology/2013/T82.pdf
http://www.vtt.fi/inf/pdf/technology/2014/T154.pdf

Article V was done within the project EcoGrad, which was funded by the Ministry of Foreign Affairs of Finland. The aim of the project was to develop guidelines for the city planning in St Petersburg for it to develop into supporting more ecological city planning. Three case districts were analysed and energy analyses were performed. A wide resident's survey was performed within the project which results have been used in this thesis. The author was acting as project manager in the project. The projects results are found in the online publication available at:
http://www.vtt.fi/inf/pdf/tiedotteet/2010/T2566.pdf

2. Literature review

The purpose of this literature review is to analyse the available literature on energy systems planning, transportation planning and urban planning and especially on literature covering these aspects holistically. These themes have been chosen since they are the core of energy efficient urban planning.

The review starts by covering literature defining the relevant terminology “Sustainability”, “EcoCity” and “Eco-Efficiency”. The topic itself is divided into the chapters covering urban planning, transportation and energy systems. An overview can be seen in Figure 1.

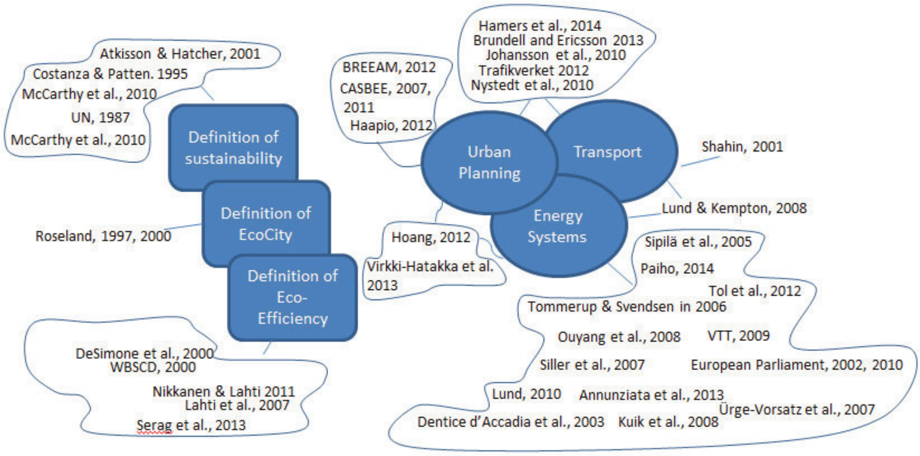


Figure 1. Overview of the literature review.

2.1 Definitions of sustainability, Eco-City and Eco-Efficiency

Costanza & Patten discuss the definitions of sustainability in their commentary paper “Defining and predicting sustainability”. It is stated that, simply put, a sustainable system is one which survives or persists. But there are three additional complicating questions: (1) What system or subsystems or characteristics of systems persist? (2) For how long? (3) When do we assess whether the system or subsystem or characteristic has persisted? (Costanza & Patten, 1995.)

According to the United Nations Commission Environment and Development, sustainable development refers to a form of development in which the use of resources meets human needs while preserving the environment so that these needs can be met not only in the present, but also for generations to come. The definition ties together a concern for the carrying capacity of natural systems with the challenges to human societies and addresses environmental issues. The United Nations Commission Environment and Development has defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (UN, 1987).

Other systems of classification have been suggested in addition to the most widely used three pillars of sustainability. Atkisson & Hatcher (2001) proposed a sustainability compass, which uses a familiar compass format but converts the directions (north, south, east and west) into the four cardinal categories of sustainability performance: nature, society, economy and well-being. McCarthy et al. (2010) proposed circles of sustainability that include indicators for economics, ecology, politics and culture.

Two decades ago the term “EcoCity” was elaborated on for the first time. Roseland M (Roseland, 1997) cites “Urban Ecology, 1996” in the paper “Dimensions of the eco city” that an EcoCity should follow the following 10 principles:

1. “revise land-use priorities to create compact, diverse, green, safe, pleasant and vital mixed-use communities near transit nodes and other transportation facilities;
2. revise transportation priorities to favour foot, bicycle, cart, and transit over autos, and to emphasize 'access by proximity’;
3. restore damaged urban environments, especially creeks, shore lines, ridgelines and wetlands;
4. create decent, affordable, safe, convenient, and racially and economically mixed housing;
5. nurture opportunities for women, people of colour [sic] and those with disabilities;
6. support local agriculture, urban greening projects and community gardening;
7. promote recycling, innovative appropriate technology, and resource conservation while reducing pollution and hazardous wastes;
8. work with businesses to support ecologically sound economic activity while discouraging pollution, waste and the use and production of hazardous materials;
9. promote voluntary simplicity and discourage excessive consumption of material goods;
10. increase awareness of the local environment and bioregion through activist and educational projects that increase public awareness of ecological sustainability issues.”

Roseland further introduces a framework for sustainable community planning as shown in Figure 2 (Roseland, 2000). This framework is based on taking social capital, natural capital as well an efficient use of urban space into account while emphasizing the mobilisation of citizens and their governments.

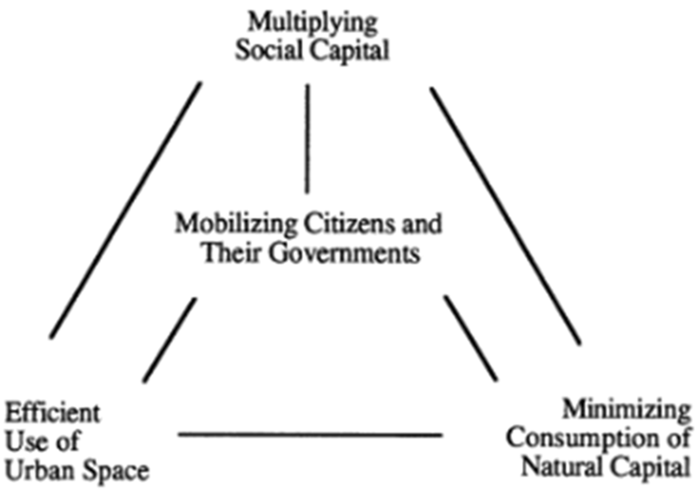


Figure 2. Framework for sustainable community planning (Roseland, 2000).

In the context of EcoCities it is also useful to introduce the concept of eco-efficiency. Eco-efficient communities aim at satisfying human needs in the community with as little environmental impact as possible (DeSimone et al., 2000). Mathematically this can be shown as the following equation (WBSCD, 2000, Nikkanen & Lahti, 2011):

$$\text{Eco-Efficiency} = \frac{\text{Values of Products and Services}}{\text{Environmental Load}} .$$

This definition was further developed by Lahti et al. (2007) instead of describing the value of products and services, to describe what these products and services are used for, that is to increase the quality of life. The factors to be minimised were in turned added to the cost factor as in the following:

$$\text{Eco-Efficiency} = \frac{\text{Quality of Life}}{\text{Harm to the Environment} * \text{Resource Use} * \text{Cost}} .$$

Serag et al. (2013) discuss the definition of the term “quality of life”, one definition highlighted being: *“Quality of life refers to the day living enhanced by wholesome* *food and clean air and water, enjoyment of unfettered open spaces and bodies of water, conservation of wildlife and natural resources, security from crime, and protection from radiation and toxic substances. It may also be used as a measure of the energy and power a person is endowed with that enable him or her to enjoy life and prevail over life's challenges irrespective of the handicaps he or she may have" (Business dictionary, 2012).*

2.2 Urban planning

This chapter starts with a description of the Finnish urban planning process. An overview of the process is of benefit for the understanding of the thesis at hand. Since each country has a bit differing urban planning process and it would be too elaborated to include a detailed analysis of several countries urban planning procedures, a choice was done to present the Finnish process.

After describing the urban planning process in Finland a review on relevant international literature within the field of urban planning is presented. The aim is to find relevant literature analysing energy efficiency of urban planning and the connection between city planning and energy systems planning.

The urban planning is based on the Land Use and Construction Law (LCL). The purpose of the law is to:

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

Figure 3 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 contains strategic decisions on a 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.)

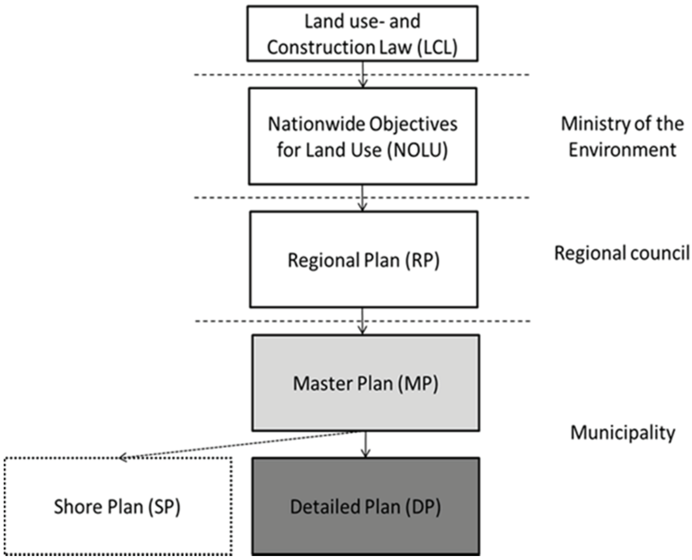


Figure 3. The hierarchy chain of urban planning in Finland (Finlex, 1999).

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 producing a master plan, a 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 gives in that sense a bigger picture that detail plans must fit into. The shore plan, on the other hand, dictates the use of shore-land (often for vacation settlement). (Finlex, 1999.)

The master plan is a general plan for directing the societal structure and land use of a municipality in its entirety. It also has to secure the inhabitants' accessibility to social infrastructure and services. 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, and good construction methods (Finlex, 1999).

A detailed plan includes a map where the boundaries are shown 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. The inspector also grants building rights, offers counselling when needed, and decides in the end when a building can be brought into service. (Ministry of Environment, 2012.)

David Hamers et al. (2014) from the Netherlands Environmental Assessment Agency discuss the importance and challenge of coherence in urban planning. Decision making is often organised in a way that decisions that affect transportation-related issues are made on a national level while urban planning decisions are made on a community level. This leads to situations where the urban planning has certain boundaries that often hinder the development of sustainable urban planning. Coherence, meaning bringing different aspects of the urban planning together, would most probably lead to more holistic and sustainable solutions. (Hamers et al., 2014.)

Henrik Lund (2010) also analyses decision making in cases where drastic changes are proposed. His study considers energy systems but can easily be adapted to urban planning since it addresses choices that impact society. He states that true choices between relevant alternatives are essential, when society is to implement political objectives implying radical technological change. Such a true choice will however not appear by itself. *"The organisations linked to existing technologies are typically the ones which take on the responsibility for proposing new projects. However, the institutional set-up of such organisations implicitly entails that they cannot generate proposals which imply radical technological changes. It is outside their discourse, interests and perception. Even if they made such proposals, it would be out of their reach to implement these. Consequently, such set-up by default does not involve true choice. On the contrary, it will repeatedly result in a Hobson's choice: Choose a project which fits well into the existing organisations or no project at all. Also, when political decisions have been made implying the wish for radical technological change, the organisations linked to existing technologies will still continue to initiate project proposals within their organisational framework"*. (Lund, 2010.) The link to the urban planning process of this statement is to acknowledge the importance of including new stakeholders that are not too much "in the existing organisation", in order to get new, more radical ideas included.

The dense city structure is essential in order to make it possible to provide daily services close to residents and a functional public transportation system. These require a certain number of paying customers to be functional. Daily services are essential when minimizing the transportation needs. A Swedish study (Trafikverket, 2012) shows however, that the densification has a rather small impact on car usage: a 10% increase in urban density reduces the usage of cars by 1–3%.

During the past few decades, various environmental assessment tools have been developed for the building sector to improve sustainability and support decision making. Recently the focus of assessing energy efficiency and sustainability of built environment has expanded from the single building level into neighbourhoods, district and even city level assessments (Haapio, 2012). There are already a large number 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).

2.3 Transportation

In this section a review on literature related to transportation in the urban environment is presented. The focus is put on literature regarding the transportation demand and especially on the urban planning's impact on transportation systems and to find literature combining transportation planning, energy systems and urban planning.

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 decrease reduction in the need for transportation, as well as an increase in the energy efficiency of transport, e.g. by affecting the use of private cars.

In Mohamed Shahin's doctoral thesis "Energy Conservation in Urban Areas in the Framework of a Sustainable Transportation Concept" (Shahin, 2001), the idea of the "push down push up" approach is introduced, meaning that the usage of private cars should decrease (push down) and meantime the use of renewable sources for the cars should be improved (push up), to contribute to more sustainable transportation solutions. (See Figure 4.)

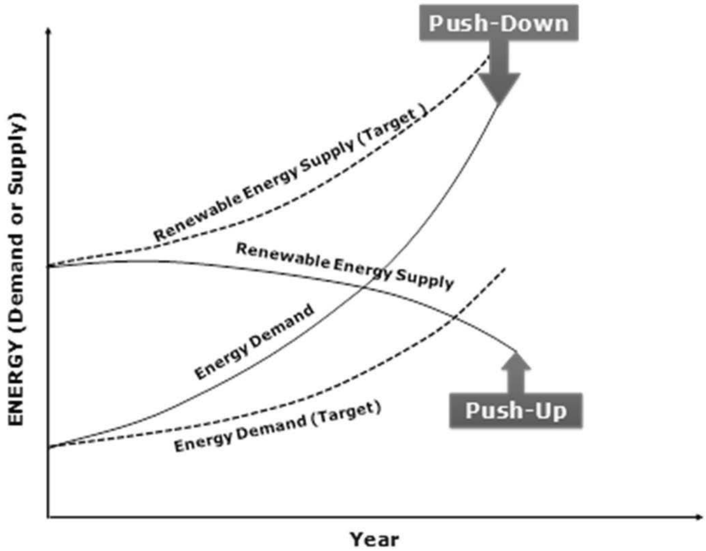


Figure 4. The Push Up & Down Approach (Shahin, 2001).

The connections between transportation and energy systems are becoming more relevant with the introduction of electric vehicles. Lund & Kempton (2008) have modelled how electric vehicles can influence the network in a positive way. The analyses show that electric vehicles with night charging, and more so with increasing intelligence including vehicle to grid (V2G), will improve the efficiency of the electrical power system, lower CO_2 emissions and improve the ability to integrate wind power. Analyses also show that end use integration, combining building and transportation end-uses, can form a coherent solution to the integration of wind power into sustainable energy systems, and that very high levels of wind power are possible, even without centralized storage or regional electric interties. (Lund & Kempton, 2008.)

In Sweden, studies have been made to investigate how different urban planning actions impact the use of private cars. The studies were collected into a report by WSP (Brundell-Freij & Ericsson, 2013). The report focuses on car use in cities only, leaving the rural areas out of its scope.

The results from the study by Johansson et al. (2010) by Trafikverket in Sweden, (Johansson et al., 2010) showed that by doubling the collective transport offering, the car use decreases by 6%. The critical length to public transport stations was, according to the study, 500 m. When the distance is longer than that, the use of cars starts to increase. It also shows that by improving cycle paths and pedestrian paths, car usage drops by 2%. Actions that can be influenced by city planning are estimated to have a potential to cut car usage by 10% divided among the following actions: by increased density of urban structure (3%), mixed functions (2%), formation and speed limits of streets to meet pedestrian and cyclist demands (1%) and by connecting to collective transportation (4%).

Another study by Trafikverket (2012) reports that a 10% increase in urban density cuts the usage of cars by 1–3%. By mixing building types, car usage can be cut by 5–15%. In practice, this means having residential buildings, services and workplaces in the same area. To achieve this, there needs to be small blocks, less than 100 m, a mix of old and new apartments and a high enough density. Parking strategy also has an impact. Good availability of parking places and cheap parking leads to higher usage of cars. As an example, it is mentioned that at workplaces with free parking car usage is up to 75% while the figure may drop as low as 15% for workplaces with no available parking. It is, however, unclear how comparable these workplaces are in terms of the demographics of the users and the geographical location of the workplace.

In some countries, there are regulations stating how far daily services can be from residential houses. In St Petersburg, Russia, it can be a maximum 500 m from each residential house to service points visited daily (Nystedt et al., 2010).

2.4 Energy systems

The literature review in this section focuses on energy systems meaning demand, transmission and production of energy. Increasing the share of clean energy production is a key instrument in developing sustainable energy systems. The optimal sources are dependent on the specific location, energy demand and available resources. Reducing energy demand in the buildings is a sufficient way to improve the energy efficiency of a district. In Europe, the regulative measures have been extensive in this matter during the last decades. Building regulations have been developed to demand more energy efficiency (European Parliament, 2010).

The objective is to find relevant literature showing the connection between energy system planning, transportation planning and urban planning.

In VTT's publication "Energy Visions 2050", it states that in the building sector the main end-uses of energy include space heating, hot water production, cooling, lighting, cooking, and various electrical appliances. It is also stated that, when improving the energy efficiency of buildings, and reducing CO_2 emissions, there are two steps: (i) reduction of building-level overall energy demand, and (ii) fulfilling reduced energy demand by utilising primarily renewable energy sources. Regarding energy supply systems, it is explained that a system for providing energy in a useful form to end-users primarily consists of an energy source, transportation (or distribution) and, in many cases, storage, energy conversion and end-use. Therefore, it can be summarised that an energy system consists of energy demand, supply and transmission. (VTT, 2009.)

In Denmark, the primary energy supply for heating is reduced to two thirds of what was used prior to 1973, even though the heated space area has increased by more than 50 per cent in the same period. This is a result of better insulation in buildings and an expansion of CHP. (Lund, 2010.)

Annunziata et al. (2013) have carried out a state of the art study of national regulations in Europe regarding energy efficiency in buildings. The study shows that European countries have adopted different approaches in the design of their national regulatory framework. Key parts of the European regulatory framework are the Energy Performance of Buildings Directive 2002/91/EC (EPBD) (European Parliament, 2002), and its recast (European Parliament, 2010). The recast of EPBD has established several new requirements such as the obligation that all new buildings should be nearly zero-energy by the end of 2020. (Annunziata et al., 2013.)

Annunziata et al. (2013) divide the policy instruments into three categories: direct regulations, economic instruments and soft instruments. Direct regulation includes standards as well as commands and prohibitions, and can be classified into: input regulation, process regulation, and output regulation. Economic instruments consist of duties, tradable emission permits, environmental liability (Kuik & Osterhuis, 2008), tax reduction and grants (Ürge-Vorsatz et al., 2007). Environmental duties can be taxes, charges, dues, or extra duties. Their function is either to increase State income, to give an incentive to the change in behaviour of the regulated subject, or to support the implementation of another environmental and energy regulation. Soft instruments include voluntary industry agreements, communication and information measures as well as voluntary certification and labelling. (Annunziata et al., 2013.)

Sipilä et al. (2005) analyse the heat trading concept, meaning that individual producers should be able to sell their excess heat to the district heating network. The concept is interesting since district heating has traditionally been a market in only the local energy utilities, which in practice have a monopoly of the district heat supply. The study shows that the challenges in such a concept are mainly related to the business models. The liberated heat energy market will also need a transmission network company that takes care of the temperatures, pressures and hydraulic balance of the heating network. The network company is also responsible for services and enlarging the network when necessary. A balance-sheet-operator is also needed to coordinate the heat contracts between producers and customers, as well as to take care of reserve capacity, spot and future markets and billing. The network operator can also be a balance-sheet-operator, especially in a small network (Sipilä et al., 2005).

Tol and Svendsen (2012) analyse low temperature district heating systems. When connecting renewable energy sources to the district heating network, the efficiency of the systems is improved when the temperature level is lower. Tol and Svendsen conclude that there are several aspects that influence the planning of the heating system. One such matter is that of determining in an adequate way the heat load in different parts of a low-energy district heating system and at different points in time. Another is that of equipping the substations of individual consumers with a storage tank that can result in a significant reduction in the pipe dimensions needed in the network in question, especially at end branches of the network, which are in a preponderance in most district heating systems. Employing a simultaneity factor at each level of a pipe segment is also shown to be useful, in particular to avoid overdimensioning, since the consumers in a district do not all consume heat at the same time. (Tol & Svendsen, 2012.) Such analyses will be hard to perform by energy utilities without sophisticated tools.

In Finland, the city plan can enable renewable electricity production but cannot enforce it. Ways of enabling it are to direct houses optimally with regard to the solar energy production potential, i.e. roofs tilted towards the south at an angle of 40–45 degrees dependent on the latitude (Hoang, 2012).

A qualitative study made by Virkki-Hatakka et al. (2013) revealed that, in public organisations, the motivation to increase energy efficiency comes, almost equally, from personal interests, conforming to laws and regulations, and customer demands. For the private sector, the customers were the main driver. In the public sector, both engineers and non-engineers agree that strategic processes are mainly bureaucratic, with tasks coming from the upper levels in the hierarchy while in the private sector, strategic processes are driven mainly by development efforts, not so much by bureaucracy or legislation. In the context of urban planning, the main stakeholders are within the public sector. (Virkki-Hatakka et al., 2013.)

Chittum & Østergaard (2014) discuss in their paper how lessons learned from Denmark can be transferred to the US in terms of including heat energy systems planning into the urban planning processes and empowering municipalities. They conclude that "*as cities aim to take control of their energy futures, it would require national governments to recognize the importance of empowering local leaders to identify the energy solutions that suit them best. DH systems in particular require a hyper-local energy analysis and benefit from local design, but offer tremendous economic and emissions reduction benefits".* It is also recognised that *"Danish heat planning rests on policies and government decisions made decades ago and continually strengthened through new legislation"*. (Chittum & Østergaard, 2014.) The importance of regulations is evident in the success story of Danish district heating systems.

> Potential renewable or partly renewable energy systems on a building scale are wood and wood pellet systems, different heat pump systems, solar energy systems, micro wind turbines and micro CHP systems. The suitability of the systems is dependent on the building and its location. To some extent the users of the buildings also determine which is the best system, while some systems require more work than others.

Micro-CHP is not yet very widely used. It has, however, been forecast that its use will become more common. The gas network plays an important role in the future prospects of micro-CHP plants. The climate also an effect on the profitability of micro-CHP plants. (Dentice d'Accadia et al., 2003.)

The first study of reduction of energy consumption through district renovations was published by Ouyang et al. in 2008. 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. (Ouyang et al., 2008.)

In her doctoral dissertation, "Energy-efficient renovation of residential districts – cases from the Russian market", Satu Paiho analyses district level renovation concepts and their impact on energy systems and the water supply infrastructure. She concludes that the possibilities for improving energy efficiency and reducing emissions through district level renovation concepts are huge, and that district renovation requires cooperation of a wide range of stakeholders. (Paiho, 2014.)

2.5 Conclusion of literature review

The objective of this literature review was to analyse what relevant literature there is within the relevant fields of energy efficient urban planning, especially on literature covering several themes holistically. The main findings are summarised in Table 1.

Table 1. Summary of main findings from the literature review.

Topic	Main findings
Definitions of sustainability, EcoCity and Eco-Efficiency	Lots of literature, minor differences in definitions. Only a few articles about the definition of “quality of life” in urban planning context.
Urban planning	Importance and challenge of coherence is highlighted in the literature. Different disciplines need to work closely together in the urban planning process. This still faces many challenges however.
Transportation	Transportation can be biggest energy consumer in a district. Energy demand caused by transportation can be reduced through urban planning measures (reduce demand, increase public transportation, enable new car technology). Transportations impact on the energy systems through a wide spread use of electrical vehicles is requiring more attention in the near future.
Energy systems	Lots of development in terms of improved energy efficiency in buildings. In Europe this has been mainly lead by regulative approach. Regulated energy market can be slowing down new innovative concepts in the energy market. But on the other hand the regulated heat market has been an important factor in the success of district heating networks. Urban planning measures can enable renewable energy systems.

The findings show that there is significant research done within the different topics addressed in this thesis, but only a few article exist that analyse both energy systems and urban planning or both transportation systems and urban planning. Relevant literature that combines all the three aspects urban planning, energy systems and transportation systems was not found at all in this literature review.

3. Research question

The objective of this thesis is to analyse the role and impact of regulations in the development of energy efficient districts and to respond to the question, "Can highly regulated planning of districts lead to higher energy efficiency if proper use is made of supportive tools? Figure 5 summarises the main research question and its sub-questions.

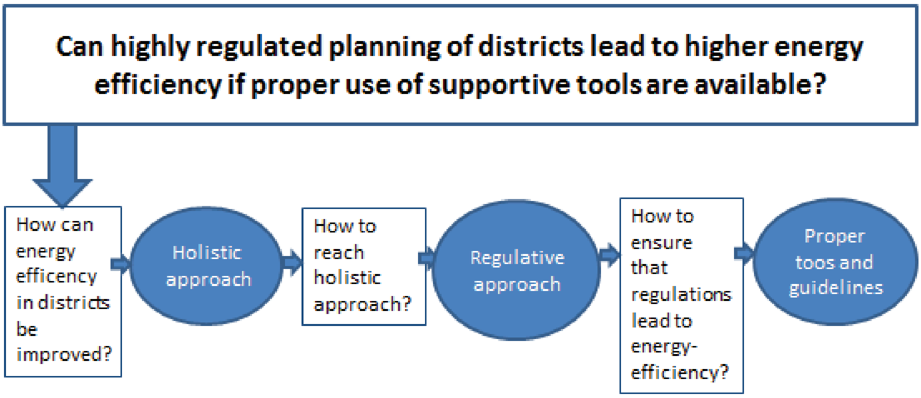


Figure 5. Research question.

The research is based on five articles which analyse the research question by showing:

1. that a holistic approach and enabling new heat trading models in the district heating systems enables a district's self-sufficiency in terms of energy. These are supporting more sustainable energy solutions in districts,

2. that tools to assess the energy efficiency of districts have been developed in order to enable city planners to easily compare detailed city plans. This enables energy-efficient solutions to be selected if a regulative approach is chosen, meaning here that energy-related issues are decided in the detailed city planning phase,

3. that to achieve a universally efficient energy solution, the entire energy chain needs to be analysed and improvements made bearing in mind the whole energy chain. Such analyses can only be carried out with a top-down approach,

4. that emissions analysis of different energy choices is not that straightforward and simple. In order for a city planner to assess these impacts, supportive tools and guidelines are needed. Through a district level regulative approach it is easier to affect heat demand than electricity demand. Quality of life is often improved through large renovation activities, which, due to the economic constraints of individual apartment owners, often cannot be performed without a regulative holistic approach,

5. that any sustainability criteria for the planning process needs to be adapted to local circumstances. More effort should be put into understanding the needs of the inhabitants. The end-user should be included more in the planning process. In Russia, there seems to be a lack of knowledge regarding renewable energy systems and technologies for building energy-efficient houses. Efforts should be put into exporting knowledge and best practices about these issues. With an increase of knowledge, the local norms can be developed in a sustainable way, and this will also support the development of the city planning process.

4. Methodology

The study is based on four journal articles and one conference paper which methodologies are briefly described in the chapters that follow. Figure 6 gives an overview of the overall methodological approach.

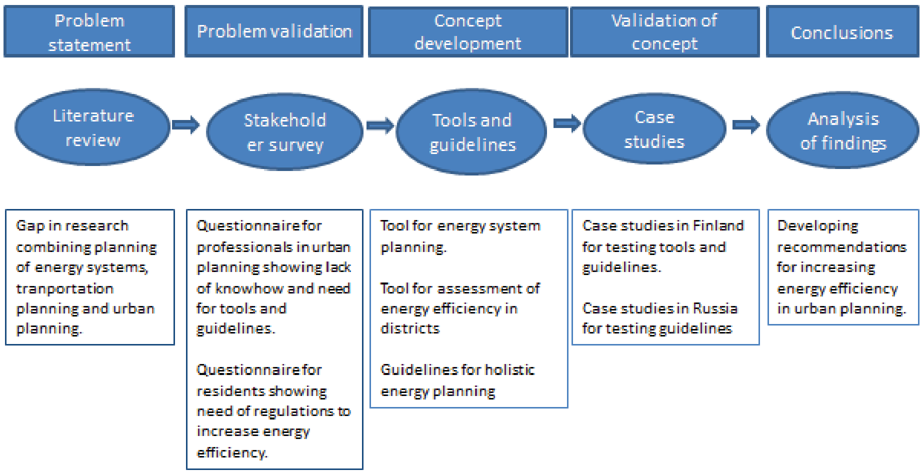


Figure 6. Overall view of the methodology used in the research.

The literature review was done by running searches on science direct with relevant key words and going through the articles found and their relevant references. Combinations of the key words “urban planning” “energy” and “transportation planning” was done in the searches in order to find literature combining those aspects. Relevant literature used in the projects where this thesis work was also analysed. Conferences were also attended to assess the state of the art within the field.

The questionnaires for professionals in urban planning and for residents are described in Section 4.1.

For an in-depth holistic analysis of the energy system in a district, an Excel based tool was developed for research purposes. To assess the energy efficiency of detailed level city plans, a tool was developed for city planners. The methodology of developing this is described in Section 4.2.

The methodologies for the energy analyses performed in the case districts are described in Section 4.3. The district level renovation activities were analysed using two different methodologies, one analysing different energy efficiency measures and another focusing on different options on the energy system and its impact on emissions. The analyses were carried out in a case district in Moscow, Russia.

In addition to the findings described in the articles, the research question has been analysed within different research projects led by the author. In the EcoNBC project, the capacity of the Egyptian University EJUST has been raised within the field of EcoCities. Many workshops, seminars and training sessions have been held where the research question raised in this thesis has been elaborated on. In the EU FP7 funded CITYTOPT project, a district level energy system optimisation application is being developed. This development process has also led to insights about the research question. In the EcoGrad project, the city planning processes of St Petersburg, Russia, was developed so as to include more ecological aspects. Findings from these projects contribute to the overall analysis of findings and the recommendations.

4.1 Methodology for stakeholder survey

A web-based questionnaire study was performed during January 2012 regarding the views of city planners and building inspectors on energy-related questions in the city planning process. The aim was to find out the level of know-how 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 building inspection and 32 from city planning. At the time of the study, there were 320 cities and communities in Finland (Kuntaliitto, 2013). The questionnaire was sent to over 300 cities and communities in Finland; 92 responses were received. 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.

The questionnaire form was created on an internet based application Digium Enterprise (http://www.questback.com/fi/) which was provided by the Questback Company.

The full questionnaire, and its results, translated to English, is included in Appendix C.

A resident's survey was done in St. Petersburg with the objective to find out residents attitudes towards energy efficiency and to clarify what residents' main wishes for their living surroundings were. The results were used in the development work of the ecological city criteria.

The survey was done together with Finec, StPetersburg state university of economics and finance. The content of the survey was done by VTT and the survey was conducted by Finec. The survey was conducted by 30 Finec Master Students in the period of 20.10.2010–15.11.2010. Each student got the task to poll at least 20 persons via e-mail/phone and at least 5 persons via in-depth interviews. The total response amount was 750 divided into 600 e-polls and 150 in-depth interviews.

4.2 Methodology for the development of tools and guidelines

4.2.1 Tool for district level energy analysis

A simple Excel-based computer program was developed in order to calculate the heat and electricity demand and production for a group of buildings for each hour of the year. The energy demand for seven different building types were imported to this tool from the IDA indoor Climate and Energy software.

Seven different building types with different consumption profiles were included in the tool (detached houses, terrace houses, apartment buildings, hospitals, educational buildings, offices, public buildings).

To each building type a cogeneration unit could be added and its operating strategy could be chosen:

- Electrical load tracking strategy: the micro-CHP plant is dimensioned according to the buildings electricity demand. The micro-CHP plant power output changes in response to the needs of the facility.
- Thermal load tracking strategy: the system is designed to follow the thermal load of the facility and dimensioned to cover the heat demand of the building. The power generated during the supply of the thermal load is used to replace purchased electricity. The excess power can be sold to the utility company.
- Electrical base load strategy: the micro-CHP plant is designed to supply the minimum amount of power required by the facility. Therefore, the micro-CHP plant can operate continuously at peak power output.
- Thermal base load strategy: the system is designed to meet the minimum thermal load. Thermal energy to meet peak loads is provided by an auxiliary heat source, such as a boiler or the district heating network. Power is purchased from or sold to the grid in order to balance the electricity demand of the facility with power supplied by a fuel cell system.

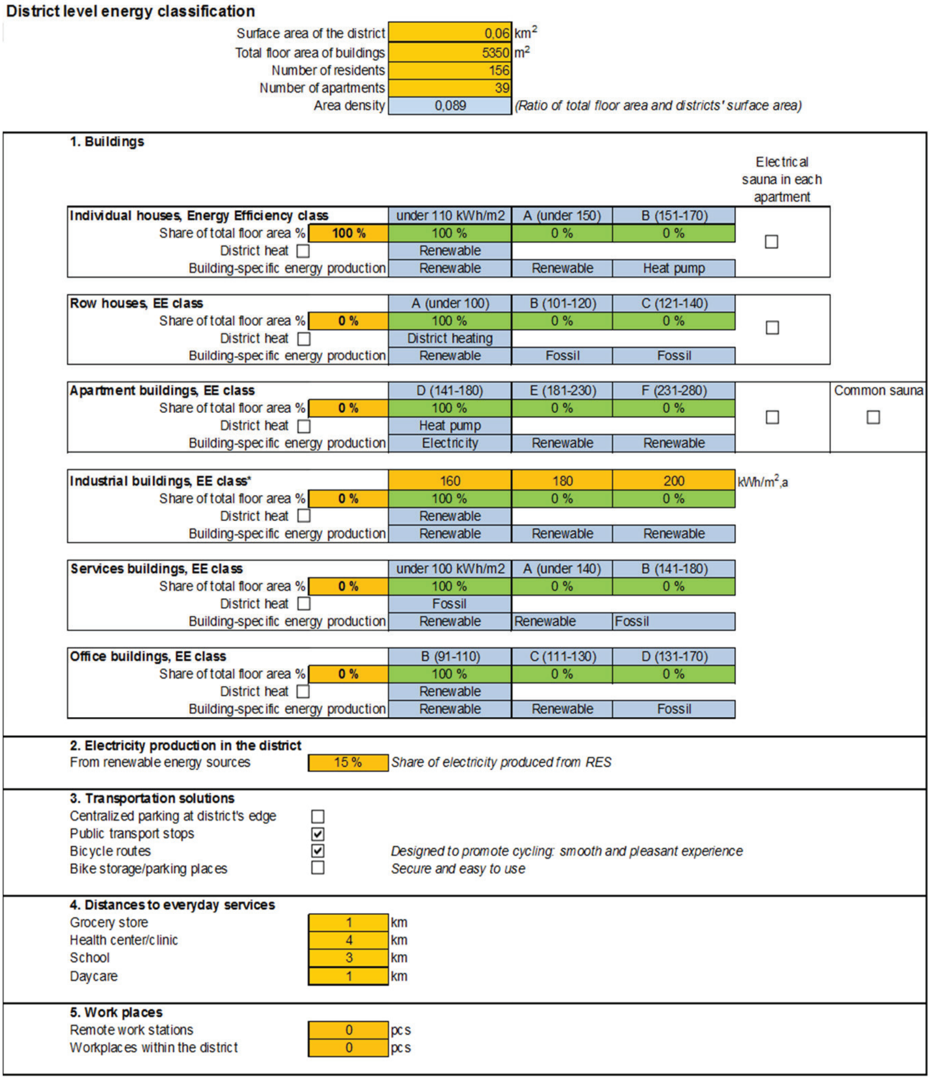
For the micro-CHP plants it was assumed that the electricity to heat ratio was 1:2, meaning that for each kWh of electricity produced there were 2 kWh of heat produced.

The tool calculates for each building how much heat and electricity the building uses and produces, and how much could be sold to the heating network each hour.

The case Kaskinen in western Finland was chosen due to the fact that the city of Kaskinen needed energy analyses done due to the shutdown of a factory which was producing heat to the district heating network.

4.2.2 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 was 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 on the internet (Jyväskylä Innovation, 2012). The input section of the tool is presented in Figure 7. An example of the results provided by the district energy rating tool is shown in Figure 8. The format of the rating resembles the energy rating of buildings used in Finland.



District level energy classification

Surface area of the district	0,06	km²	
Total floor area of buildings	5350	m²	
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 in each apartment	Common sauna
Individual houses, Energy Efficiency class		under 110 kWh/m2	A (under 150)	B (151-170)	☐	
Share of total floor area %	100 %	100 %	0 %	0 %		
District heat ☐		Renewable				
Building-specific energy production		Renewable	Renewable	Heat pump		
Row houses, EE class		A (under 100)	B (101-120)	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, EE class		D (141-180)	E (181-230)	F (231-280)	☐	☐
Share of total floor area %	0 %	100 %	0 %	0 %		
District heat ☐		Heat pump				
Building-specific energy production		Electricity	Renewable	Renewable		
Industrial buildings, EE class*		160	180	200	kWh/m²,a	
Share of total floor area %	0 %	100 %	0 %	0 %		
District heat ☐		Renewable				
Building-specific energy production		Renewable	Renewable	Renewable		
Services buildings, EE class		under 100 kWh/m2	A (under 140)	B (141-180)		
Share of total floor area %	0 %	100 %	0 %	0 %		
District heat ☐		Fossil				
Building-specific energy production		Renewable	Renewable	Fossil		
Office buildings, EE class		B (91-110)	C (111-130)	D (131-170)		
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

Figure 7. The input sheet in the rating tool (Article II).

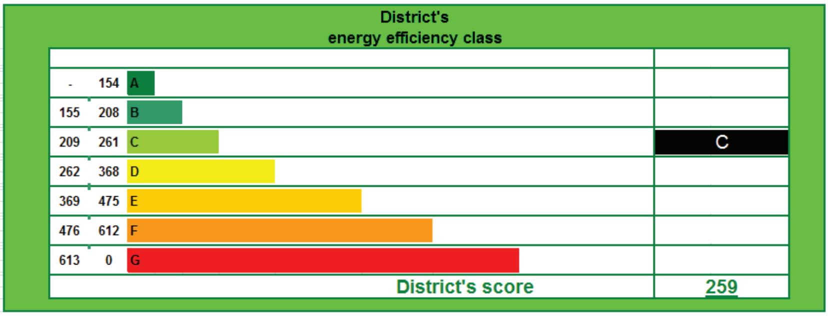


Figure 8. The result diagram of the district energy rating tool (Article II).

The energy efficiency rating is based on primary energy consumption, in order to take into account both energy demand and used energy source. This is done through the use of energy conversion factors used in the calculations of the E-number, listed in Table 2. The tool is designed to compare different solutions within one district; therefore, results comparing different districts are not comparable with each other in terms of energy class. The primary energy factor however shows the primary energy used per built square metre and can be used for comparing districts. In order to gain a good understanding of the expectations for the tool, discussions were held with city planners from five case rural districts in Finland. Additional to these interviews, the results from a questionnaire that was carried out among city planners were used.

City planners often have no building technology background, meaning lacking technical understanding of HVAC technology, construction technology and energy systems in buildings. In order for them to be able to assess the energy demand of buildings, the energy labels assigned by energy certificates were used. 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 real energy use is naturally dependent on the residents' behaviour and the sizes of the families living in the houses. It needs to be stated clearly 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, Ministry of Environment, 2012.)

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 detail 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 heater is normally 6 kW. The tool has options for electrical or wooden heated saunas. In multi-apartment buildings, whether all the apartments have their own saunas or whether the apartment has one common sauna can be selected for. Saunas are culturally very important to the Finnish people. Even in new small city apartments, small saunas are prevalent. 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 single family houses. There are, however, ways to increase the energy efficiency of saunas by reducing the numbers and the usage of the individual saunas by offering a nice common sauna in the neighbourhood. Planning a nice luxurious common wooden heated sauna in the area, for instance by lake shore, can be a better alternative than small individual electric saunas in each housing unit.

To ensure the simple usage of the rating tool, the heating energy source could be chosen from the following: renewable energy systems, heat pumps, fossil fuels and electricity. Similar classifications of the energy sources used and their energy conversion factors are used in the Finnish building regulations from 2012 (Ministry of Environment, 2012). Energy sources used and their energy conversion factors are shown in Table 2. These energy conversion factors aim to represent the primary energy consumption of different energy sources in Finland. The Finnish electricity production mix is partly used as basis in the development of the primary energy factors. (Statistics Finland, 2011.)

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

Table 2. Energy conversion factors in Finland that are used in calculating the E-numbers (Ministry of Environment, 2012).

	Energy conversion factor
Electricity	1,7
District heating	0,7
District cooling	0,4
Fossil energy sources	1
Renewable energy sources (including wood and other bio fuels)	0,5

For ground heat pumps, an estimation of the annual 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 the energy consumption of buildings, if a better performance of heat pump cannot be proven (Ministry of Environment, 2007). The electricity that the heat pump uses is converted to primary energy with a factor of 1.7 according to Table 2. The heat distribution losses of a district heating network are analysed on a rough level (Article II), see Figure 9. This is done by analysing the statistic of all Finnish district heating network statistics provided by the Finnish Energy Industries (Finnish Energy Industries, 2009). 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. This is due to the increased energy consumption per distance of district heating network. This dependency was taken into account in the tool. If a district heating system was chosen as the energy system used in the tool, the estimation of heat distribution losses was added to the total energy demand.

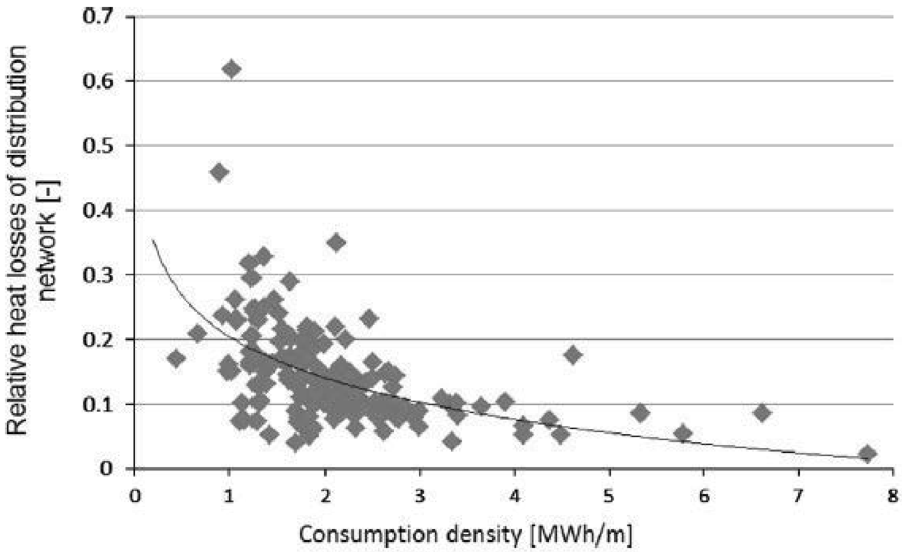


Figure 9. The estimated ratio of the density of energy consumption and the relative heat distribution losses (which are relative to the total energy production) of district heating networks in Finnish cities (calculations based on data from Finnish Energy Industries, 2009).

In addition to renewable heat sources, renewable electricity production was also 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 be able to assess how much of the electricity needs of a district can be covered locally in the district with different installations of photovoltaic panels or wind turbines. In order to acquire actually realistic and accurate energy production potentials, simulations would be needed. There are, however, as yet no suitable simulation tools for the city planners for this purpose, and they might lack the knowledge to make such simulations. Moreover, the target of the rating tool is to give an estimate quickly and easily of the overall energy efficiency in the initial planning phase of a district.

In this tool, energy use caused by transport was considered only in regards to transport performance that can be influenced by the detailed city plan, which means that the focus was on the transport inside of the district. Solutions studied in the detailed plans are: centralised parking in the outskirts of the district, bus stops, proper and separate ways for walking or cycling and storage spaces for bicycles. The effect of the actions aiming to reduce the use of private cars was estimated on the basis of the modal split research results of the City of Freiburg, Germany. (Bindra & Giel, 2006.)

The distance to daily services and the number of workplaces in the district influence the transport demand significantly and were taken into account in the tool. The methodology for this is further specified in Article II. The energy efficiency rating was calculated by multiplying the energy consumption of the buildings and possible distribution losses of the 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 in the total primary energy demand of the district. The calculation procedure is shown in Equation 1.

$$\text{E-number} = \frac{\sum_i \left(E_{\text{cons},i} - E_{\text{prod},i}\right) f_i + E_{\text{trans}}}{A_{\text{net}}} \tag{1}$$

Where

i =	Energy source
E_{cons} =	Energy consumption [kWh]
E_{prod} =	Energy production [kWh]
f =	Energy conversion factor
E_{trans} =	Energy consumption of transportation [kWh]
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, 2012.) By putting input values describing the best available solution in terms of energy efficiency we define this as the A-class, and the worst case scenarios values give us the G class. The classification is then linearly divided between these.

The tool was tested in 5 different districts. The case districts were chosen by the communities that were involved in the research project. The districts were such that were in detailed planning development phase at the moment of the research and where special energy efficiency measures wanted to be analysed.

4.2.3 Creating a concept for ecological criteria for city planning

First a basic concept, based on Finnish base data, was developed. It was further developed in a workshop with the local authorities. Based on the workshop adjustments were made. The concept was refined by adjusting it to three different pilot cases. The detailed concepts were again presented to locals and adjusted. The development process could be called an iteration process. Input for the concept development was received also from the survey explained in Section 4.2.1.

For each pilot case, a plan of the area was made, including the structure of the area, building types and location of services as well as transportation solutions. Different energy systems were modelled and compared. As a first step, the base data was collected and a plan of the area was prepared. The number of inhabitants, buildings and necessary service spaces were determined. The cases were chosen by the local partner, the city authorities, according to the desire to develop certain areas in the city.

As a second step, energy consumption of the entire area was calculated in different scenarios: base case scenario, low energy building and/or passive house level. The consumption level of base case scenario was assumed to correspond to the energy consumption level of Finnish building regulations in 2008, because reliable sources about Russian consumption levels were not available. Consumption levels of low energy and passive houses were also based on Finnish definitions (Strom et al., 2006, Nieminen & Lylykangas, 2009). The energy consumption was calculated using the WinEtana program, which has been developed by VTT (Kosonen & Shemeikka, 1997).

Different options for energy production, based on renewable energy sources, were studied. Different suitable production technologies were recognized, and then emissions produced during the entire lifecycle of the energy production process were calculated and compared with each other. In addition, distribution losses were also included in the calculations. The emissions from the energy production were calculated using the GEMIS tool (Global Emission Model for Integrated Systems), developed by The Öko-Institut e.V. GEMIS is a computer program allowing to model life time emissions of technological processes, including construction transportation, etc. The program uses a large database containing various technological parameters and amounts of emissions related to those.

4.3 Methodology for district level energy analyses

4.3.1 District level energy efficiency analysis

The general methodology of energy analyses done in the Moscow case districts is shown in Figure 10. 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 were built between 1966 and 1972.

A few different typical apartment building types were 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 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 were acquired. The last phase of the energy chain analysis 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.

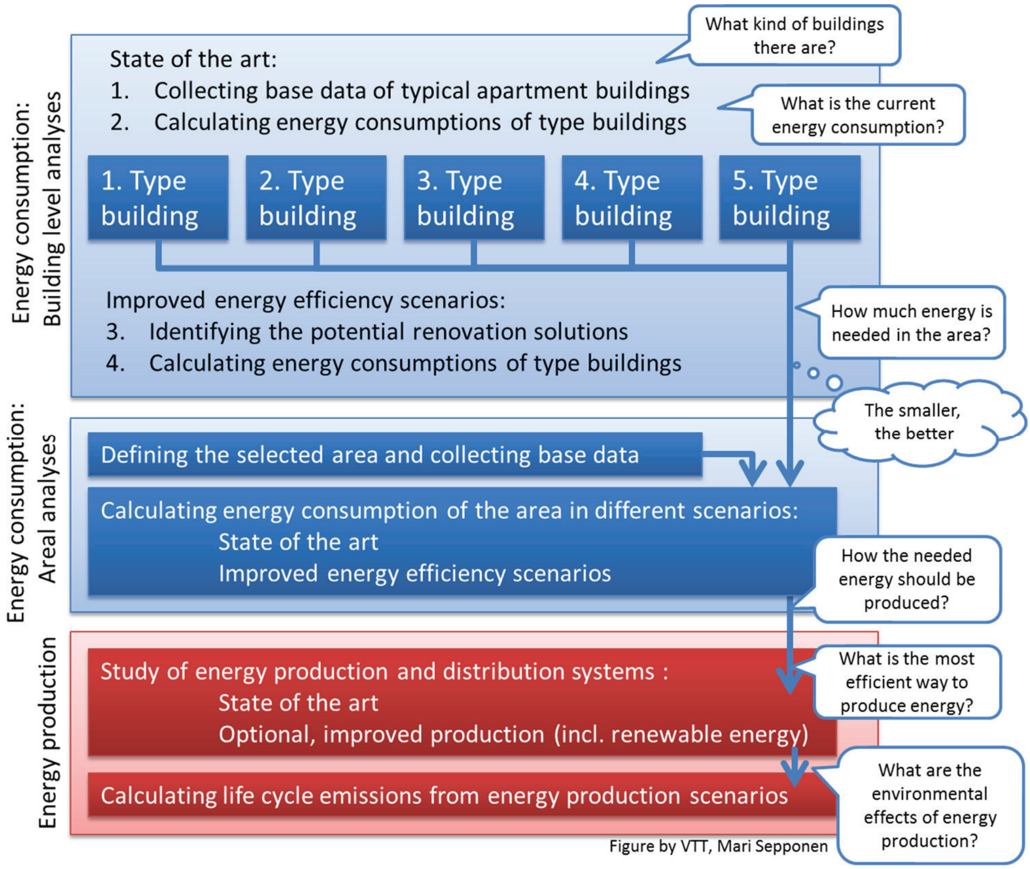


Figure 10. Methodology for district level Energy analysis (Article III).

4.3.2 Methodology for district level energy and emission analyses

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 the 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 Figure 11.

After the energy demands were analysed, the life cycle emissions for different energy production scenarios were calculated including CO_2-equivalents, SO_2-equivalents, TOPP-equivalents and particle emissions.

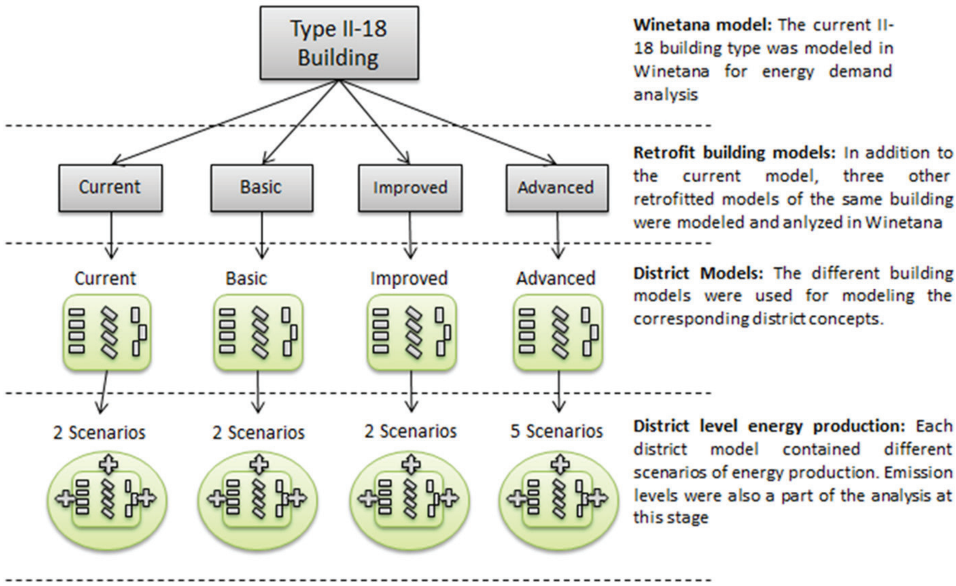


Figure 11. Overview of the energy analysis process in the study. WinEtana is a computer software for building level energy demand analyses developed by VTT Technical Research Centre of Finland Ltd.

The apartment buildings in the analysed 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 (Opitz et al., 1997). 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 Article III.

5. Findings from the analyses

The studies described in the articles all analyse district level energy systems including energy demand, transmission and production. The studies analyse the issue from different perspectives and with somewhat different objectives. All the studies show that it is possible to achieve major improvements to business as usual with the help of good analysis tools and a holistic approach. In Figure 12 a visualisation is done to show how the findings from the analyses relate to the overall research question.

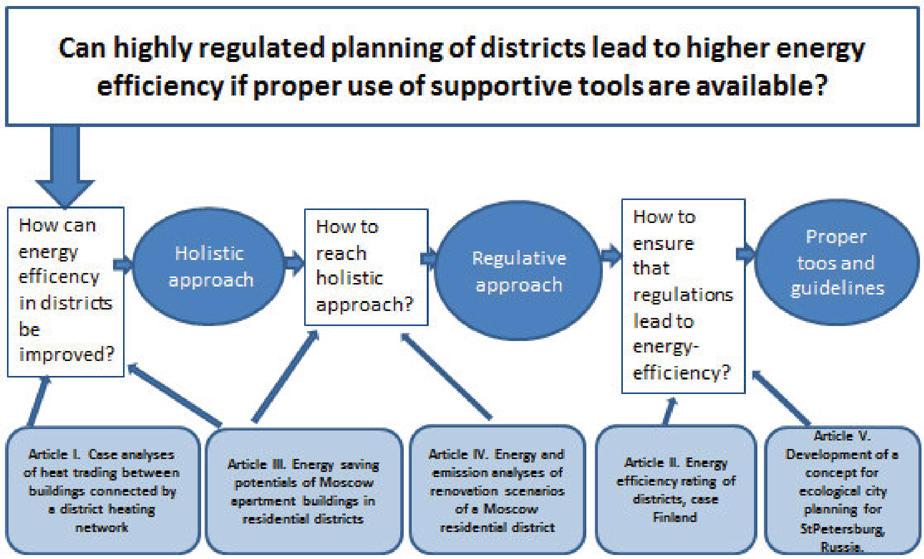


Figure 12. Findings from the analyses and their connections to the overall research question.

5.1 Questionnaire and residential survey

The questionnaire done to city planning professionals showed that there is a certain lack of knowhow about energy related issues. For example the term "primary energy" was familiar to only a bit more than half of the respondents. Some energy systems were not very familiar for the city planning professionals. The assessment of different energy alternatives for a district is considered a challenge for this target group.

According to the questionnaire there seems to be a will to develop districts into more sustainable ones. Self-sufficiency in energy and reduced emissions both received more acceptance than easiness of getting building lots sold.

Regulative approach seems to be rather well accepted in this group. Giving builder large freedom to build what and how they want was not considered important.

The residents' survey done in St Petersburg, Russia showed that the majority of people are not willing to pay any extra for improved indoor comfort even if it is considered important. Renewable energy as a heat source for the house is not considered important for the residents. Green areas and safety issues are on the other hand important.

The details of the questionnaire and residents survey results are found in Appendix C.

5.2 Detailed energy systems analyses

The detailed results of the analyses are described in Article I.

The central part of the city of Kaskinen in south-western Finland was used as the case example in the analysis. The energy demand was simulated based on seven different building types. The types were chosen based on the real situation in the chosen area. Different energy production scenarios were analysed and compared with each other. The aim was to analyse how optimal energy system could be designed if heat trading were possible using the existing district heating network.

The simulations showed that heat trading could be a functional way to develop decentralised energy systems. There is a potential advantage when buildings, with consumption profiles that are different in shape and/or timing, are connected through a district heating network. However, it is unlikely that this potential could be utilised by simply providing a micro-CHP plant for every building. A holistic approach to dimensioning and control strategies in different buildings will be needed as well as a smart mix of buildings with and without CHP plants. A possibility of using thermally activated cooling in the district heating network could be considered as a supplementary measure for use of the excess heat in summer.

Theoretically, heat trading could be a functional way to improve the financial prospect of micro-CHP plants. Having a way to sell the excess heat production improves cost-effectiveness. However, there are obstacles since the heat market is not yet a free market but is still a regulated one, which is a major obstacle to a functional heat trading. Having a fuel cell system with no CO_2 emissions also gives the opportunity of selling emissions quotas. This is, however, one kind of a micro-CHP technology which has still many obstacles.

If heat trading were a reality, there would be a need for some party to manage the whole trading system. The energy companies seem naturally suited for this, since they have the know-how about the district heating networks and their functionality. It seems as they see the heat trading concept as a competition to their business.

One serious possible obstacle to widely spread heat trading is that micro-CHP plants often use natural gas as a fuel, which means that they usually have to be connected to a natural gas network. At the same time, the building has to be connected to a district heating network in order to sell off its excessive heat. It is quite rare in Finland (but not e.g., in Central Europe) that we have both a natural gas network and a district heating network at the same location.

The study showed that heat trading could be a functional way to develop decentralised energy systems. There is a potential advantage to be utilised when buildings with consumption profiles different in shape and/or timing, are connected through a district heating network.

5.3 Energy efficiency rating of districts

In this study, a tool for assessing the energy efficiency of detailed city plans was developed. The tool was used in five case districts analysing different planning options and assessing how different options impact energy efficiency.

The detailed results of the analyses are described in Article II. Below (see Table 3) some results related to the energy systems in the districts are described.

In Table 3 the results of the energy systems analysis in one of the case districts, Säynätsalo is shown. Rows 1 and 2 show that the primary energy factor increases significantly when the energy source is changed from renewable to fossil fuel. The impact of renewable electricity production is seen on rows 5–9. It is interesting to see that the same total primary energy factor is achieved by having no renewable electricity production but heating 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 the 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.

Table 3. Energy system analysis in the Säynätsalo case district.

Case	Local heat network	Heat Source	Renewable electricity production	Total primary energy need [kWh/m2]	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

In Table 4 the impact on different energy solutions on the building level is shown. In all calculations, there were building specific heating systems, distance to daily services were 0 km, public transport and cycle lanes were considered in the plan, and there were 50 working places in the district for all cases.

As can be seen when comparing rows 1 and 2 and 3 and 4 in Table 4, the impact on the energy class is significant when changing the heating system from renewable to 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 should be emphasised that, even though the annual primary energy demand does not differ too much, when saunas are used widely and during same time periods, as is the case typically in Finland, the impact on the electricity peaks can be significant and affects the whole energy system. Comparing rows 7 and 5 shows the impact of building high rise buildings instead of single family houses. The difference is high since high rise buildings consume less heating energy per residential square metre.

Table 4. Impact of buildings energy solutions on the districts energy efficiency rating. Case Säynätsalo.

Case	Building type	Buildings energy class	Heat Source	Sauna?	Total primary energy need [kWh/m2]	Total rating
1	Single family	A	Renewable	no	142	A
2	Single family	B	Renewable	no	152	A
3	Single family	A	Electricity	no	262	D
4	Single family	B	Electricity	no	296	D
5	Single family	A	Renewable	no	142	A
6	Single family	A	Renewable	yes	153	A
7	High rise	A	Renewable	no	117	A

The tool developed is a simplified one that gives practical help for city planners in assessing 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 with regard to energy efficiency. It needs to be highlighted though that the tool does not take into account the location of the district and thus not be used to assess the overall energy efficiency of living in the district. Another tool or guidelines is 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 should also be emphasised. Heating systems can be changed at later stages of the building's lifecycle more easily than the energy efficiency of the house can be improved. A major part of the energy use in the district is in the end influenced by the actions of the people living there.

The developed tool evaluates the environmental sustainability of a district by analysing its primary energy demand. The tool guides on cutting the primary energy demand of the area, when targeting to get better classification from the tool. This primary energy demand evaluation includes the energy demand of buildings and transportation as well as the energy system and source used. Even though the tool itself does not estimate CO_2 emissions from the area, it still contributes towards this goal. Firstly, if the energy demand of buildings is reduced, it similarly reduces the emissions from energy production caused to cover the demand. Similarly, emissions reduction results from the energy demand of transportation, as its energy efficiency can be improved or transport needs cut. Furthermore, the primary energy analysis tool takes into account the energy source used via Finnish energy conversion factors, which are valued partly based on their environmental impacts.

5.4 District level energy efficiency analyses

The district heating network has a great potential for improving the energy efficiency, because there are many heat losses in the heating network at the present day when analysing the case in Moscow. One important renovation target is to install completely automatic individual substations in every building and so move from the old four-pipe to new two-pipe district heating systems (Eliseev, 2011) 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%. In addition, the CO_2-equivalent greenhouse gases may be reduced by up to 65%. To achieve a universally efficient energy solution in Moscow, the entire energy chain needs to be analysed and improvements made bearing in mind the whole energy chain. The results of the study in Article III showed that improved indoor conditions and reduced heating consumption often lead to increased electricity consumption. This is due to the fact that improved insulation and airtightness which lowers heat demand and reduces draft, often is done together with the installation of mechanical ventilation to ensure a proper ventilation of the building. The ventilation system increases the electricity use. By analysing the energy efficiency of indoor conditions and the building overall energy efficiency instead of energy consumption, the issue of increased electricity consumption is put in the correct context and the improved “output” of the consumed energy is properly considered.

5.5 District level energy system analyses

At the district level, different improvement scenarios in terms of energy demand, energy production and emissions were analysed using a case district in Moscow as a case study. Different scenarios were developed and analysed. The analyses showed that great energy savings could be achieved in a district through different modernisation scenarios. The basic district concept showed a total annual electricity demand reduction of 24%, and a total reduction in heating demand of 42%. The improved scenarios gave results like 33% and 55% reductions for electricity and heat. The most advanced scenario reached a heating demand reduction of 72%, while the electricity reduction stayed at 34%. One reason for this is that electricity usage of residential districts is greatly influenced by people's behaviours while heating demand can more easily be influenced by technical measures.

The importance of analysing the whole energy chain became evident in the analyses when looking at cases where heat losses in the heat distribution network were very large and heat exchangers were lacking between networks and the buildings, as is often the case in Russia. This leads to a solution where the reduced energy demand in a building does not lead to savings at the beginning of the energy chain, but might instead even lead to overheating of the building.

The emission analyses showed 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 a greater reduction than implementing more advanced renovation solutions. However, doing so would on the other hand also result in twice the amount of produced SO_2 equivalents and particulates. To conclude, 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.

5.6 Concept for ecological city planning

The criteria list for an EcoGrad area was made based on the findings from the discussions with the local city planners, the residents survey done and the development of pilots. It included aspects from the international LEED and BREEAM criteria and national Finnish criteria (LEED, 2011, BREEAM, 2012). These findings are discussed below.

The criteria list is divided into the following sectors: the structure of the area and land usage, landscape, buildings, energy, transportation, waste and water solutions. There are three categories in the criteria list: general level criterion, details and specifications of the criterion and special notices from St Petersburg. Here the differences between Finnish and Russian criteria were addressed.

Less focus can be put on the placement of services due to the fact that the norms already require that the services are placed close by. The need for cycle routes is included, despite the fact that cycles are seldom used. To support the use of cycles, security issues should be highlighted, both in terms of traffic security meaning separated lanes for cycles and in terms of safe parking solutions to prevent the cycles from being stolen.

The criteria setting includes that renewable energy sources should be examined. It has, however, become clear, that the development of renewable energy systems is not that common yet in Russia. One aspect was that the buffer zones for bio energy plants were not known by Russian partners. It was also a little unclear whether energy wells could be drilled for the use of heat pumps according to the local legislation.

The passive house solutions need to be highlighted here. An important part of the passive house concept is the mechanical ventilation with efficient heat recovery. It needs to be emphasized that buildings cannot be built airtight and well insulated unless the ventilation is in order.

Generally speaking, it seems that passive solutions that are not that technology dependent are valued higher in Russia. Technological solutions are not considered to be ecological, but on the contrary they are seen as potential additional electricity consumers, mechanical ventilation being one example of this. Smart metering systems for electricity use were of interest but still considered with some scepticism.

As an example of the energy system, calculations of one pilot are briefly introduced below. The planned number of inhabitants in the area is 20,000. The residential area is 30 m^2 per inhabitant, which means in total 600,000 m^2 floor area. There are five different building type areas: dense, low and dense, detached houses and villas. The occupation is densest in the centre of the area, which is really close to services and railway connection to the centre of St Petersburg.

The energy consumption has been calculated in three different scenarios: base case, low energy and passive building levels. The results can be seen from Figure 13. Most significant improvements are related to cutting the heat consumption of buildings, and especially the heat consumption of space heating. It is more difficult to affect the electricity or hot water consumption, because they depend more on the habits of the residents.

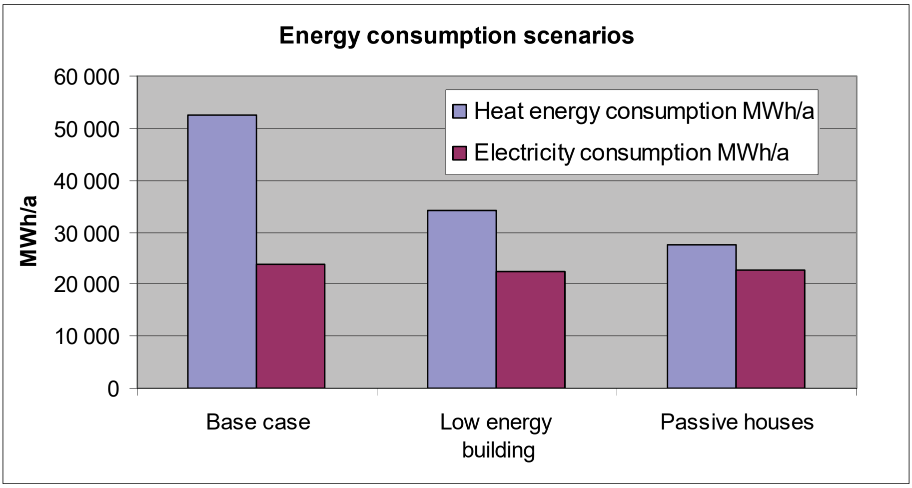


Figure 13. Energy consumption of the pilot area in different scenarios.

Next, different energy production options were studied. The first option was quite extreme with the target of using only renewable energy sources and achieving as low an emission level as possible. That meant ground heat pumps, building-integrated solar panels and wind power.

Heat collection pipes could be mounted on the golf court located close to the pilot area. It was assumed that the COP of the heat pumps is 3, and the heat yield is 35 kWh/m^2/a. One of the challenges was the fact that heat pumps consume electricity, which is also supposed to be produced within the area. If was further assumed that the entire area of roofs could be utilized with building-integrated solar panels. It was calculated that the yield of the solar panels would be 17,700 MWh/a. This means that there should also be a lot of wind energy: in a base case 28,804 MWh/a (the power capacity being 14.4 MW), low energy building level 20,200 MWh/a (with the power capacity of 10.1 MW) and passive building level 17,796 MWh/a (with the power capacity 8.9 MW). The power levels of wind power are calculated with a capacity factor of 23%. In this option the target was to produce as much energy as is consumed in the area, but it is assumed that the area is connected to the national electricity grid, which evens out the differences between the production and consumption continuously.

The second option was a combined heat and power production (CHP) plant fuelled with woodchips. The third option was also a CHP plant, but fuelled with biogas produced from the wastes. It was assumed that the CHP plant is operated according to the heat demand in the area, as usual. In addition, it was assumed that the plant produces 80% of annual heat consumption, and the rest of the heat demand is covered with reserve plants, for example a natural gas boiler. The CHP processes used were calculated with information from real existing plants from the database of the

GEMIS software. The plant using wood as a fuel produced 2 MWh of heat per 1 MWh of electricity, with an electrical efficiency of 27.5 % and operating time of 6000 h/a. The biogas CHP plant produced 1.5 MWh of heat per 1 MWh of electricity, and the efficiency and operating time were the same as the woodchip CHP plant.

The greenhouse gas emissions of these different energy production options are shown in Figure 14. The emission calculations include the emissions produced during the entire life cycle of their processes (including, for example, construction and transportation). These results were also compared to the base case, which represents the current situation in Russia. According to IEA, in Russia buildings are heated most commonly with district heating, in which the heat is produced from natural gas. The emissions of base case electricity are calculated with GEMIS from the base data of IEA (IEA, 2008).

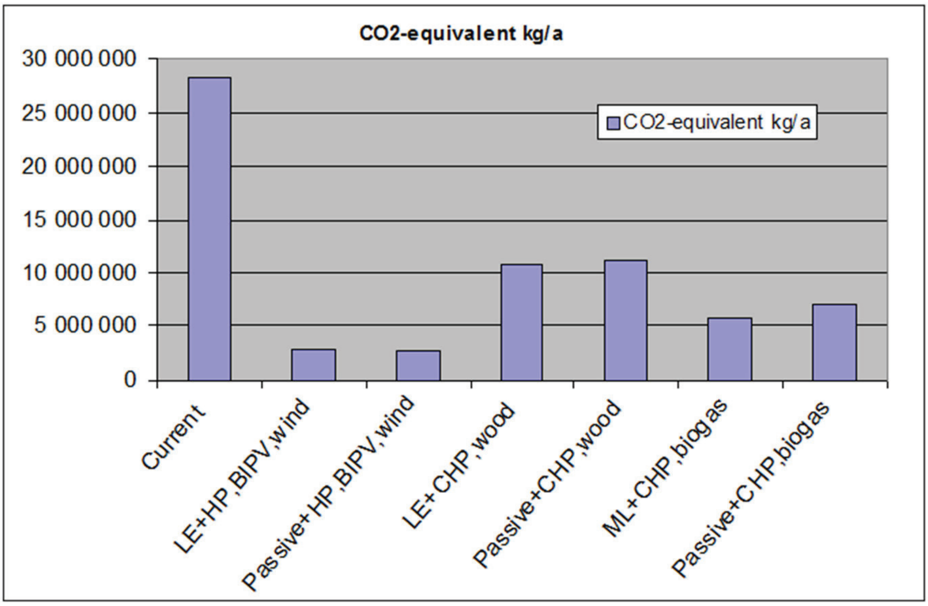


Figure 14. Greenhouse gas emission from different energy production options in the first pilot case. (LE = low energy buildings, Passive = Passive buildings, HP = heat pump, BIPV = building integrated solar panels, CHP, wood = CHP plant that uses woodchips, CHP, biogas = CHP plant that uses biogas.)

5.7 Summary of findings

Energy efficient districts is a wide research topic. The topic has been analysed in the journal and conference papers mentioned earlier. The analyses consisted of questionnaires, surveys, energy analyses, tool development and the development of an EcoCity concept. The main findings of the analyses relevant for this thesis are summarised in Table 5.

Table 5. Summary of main findings from the analyses.

Topic	Main findings
Questionnaire and residents survey	City planning professionals experience a lack of knowhow about energy-efficiency and renewable energy systems. Supportive tools and guidelines are needed. Green areas are valued and safety is considered a problem. Residents in St Petersburg, Russia don't value renewable energy very highly and are not willing to invest in that. In order to push renewable energy and energy efficiency other than voluntary market based action is needed.
Detailed energy system analysis	Heat trading could be a functional way to develop decentralised energy systems. There is a potential advantage to be utilised when buildings with consumption profiles different in shape and/or timing, are connected through a district heating network. Holistic approach to energy system planning is needed to achieve these benefits.
Energy efficiency rating of districts	Energy efficiency of districts can be improved by changes made in the detailed city plan. The assessment tool developed helps the city planners improve the energy efficiency.
District level energy efficiency analysis **District level energy system analyses**	To achieve a universally efficient energy solution, the entire energy chain needs to be analysed and improvements made bearing in mind the whole energy chain.
Concept for ecological city planning	Concept can be based on general global concepts but have to always be localised. Analysis of energy systems is a key factor in order to find the best solutions for an ecological district.

6. Discussion

The research question was whether energy efficient urban planning can be supported by a higher degree of regulations. The main research question was analysed by analysing whether a holistic approach to energy system planning could be beneficial in this aspect, leading to the question whether a regulative approach is needed to achieve a holistic approach. The role of tools and guidelines steering the regulations in the right direction was the follow up question.

In this chapter these questions are discussed based on the findings from the analyses described earlier, following the life cycle of the urban planning process from regional planning phase to renovation of existing districts.

Different stages of the urban planning process can determine different aspects related to energy efficiency and sustainability. Below these phases are discussed from a Finnish perspective (summarised in Table 6) with some further discussion looking at the topic in a wider, international context. It should be noted that urban planning processes differ from country to country. In general, the planning is done on different levels with more national level decisions being made in general plans and the decisions moving down to the community and even individual level when the scope narrows to city plans, detailed city plans and plans of blocks and houses.

6.1 Regional planning phase

In the regional plan, decisions are made related to major infrastructures on a regional level and some base principles related to placement of daily services, for example the decision on whether the city is allowed to plan big food markets outside the city centre. This is an example of a decision that, when being made looking at the cities short term economic benefits, might lead to a non-sustainable solution in the long term. Therefore, it is positive that such decisions are made on a regional level and are not being steered by a city's short term interests. Major transportation-related decisions are made in this phase also as are decisions related to railways and other regional logistics infrastructure. These are all aspects that have a major influence on the mobility of people and have a great effect on emissions and energy efficiency. In recent years there have been examples of regional plans that better take sustainability into account, one example being a stricter approach to daily services being placed outside of city centres. There are, however, still improvements to be made in this; the interpretation of the legislation in these aspects can vary a great deal among planners. Assessment tools for assessing the impacts of different planning decisions are needed in order for the effects on sustainability to be more easily known and therefore the decisions being more accepted also at the city level.

When assessment can be made more precise with agreed objective tools and methods, the legislation can also be more detailed and will be less dependent on individual planners' interpretations and mind-sets.

6.2 Master planning phase

The master planning is done within the community. It draws on the main principles of a chosen area regarding what type of use the area shall be put to, also called zoning. The master plan draws up the plans related to public transportation. In regard to energy systems, decisions on building a district heating network for a district are taken in the master planning phase.

Regarding transportation, the main principle in the master planning phase should always be to have public transportation, cycle routes and pedestrians as first priorities. Infrastructure for private cars should be planned as the "second or third" option only. In the city of Porvoo in southern Finland, the master plan of the area Skaftkärr is a good example of where this thinking has been realised. Even though the area is –6 km outside of the city centre, the master plan was prepared based on bus transportation and good cycle routes. In the first realised detailed plan in this area, the master plan principle was followed by planning the fastest and most direct routing for the public transportation and cycles only. Private cars were directed to another route. This was, however, not a simple process. The shift from a master plan decision to detailed plan realisation was not clear to decision makers. The same decision makers that had approved the master plan were opposing the detailed plan even when the detailed plan was only realising the master plan. This is an example showing that more guidelines and tools are needed to show the impact of decisions. Ways to show what master plan level decisions mean in practice on a detailed plan level are also needed. In the Porvoo case, this was not clear for all. Most decision makers agreed on the overall principle but could not understand the practical implications. This is, of course, natural since decision makers are not experts in city planning.

The energy systems are to some extent being addressed in the master planning phase. Details are left for the detailed planning, but the main principles can be laid down already in the master plan. The district heating network is often addressed in this phase. As discussed in Articles I, III and IV, the more holistically the energy systems are planned, the more likely they are to achieve efficient solutions. The collaboration between energy utilities and city planners could often be closer in this phase. In order for the city planners to assess the efficiency of different planning options, they need input from the energy utilities, for example when assessing the transmission losses of the network. The energy utilities might benefit if the collaboration could lead to planning of a type that is most beneficial for the installation of the heating network. It should also be noted that district heating should not be considered automatically to be the best solution; other options should naturally also be considered. The local energy utility could also play a role in other options by developing their service and business concepts.

Through innovative business models, renewable energy can also be promoted. For example, in that the local energy utility invests in local renewable electricity production installed in buildings. A model worth considering could be that the energy utility rents the roof space of the buildings and owns the photovoltaic panels and handles everything regarding 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. One issue to discuss is whether a highly regulated environment gives enough freedom for developing such new ways of doing business? When applied wisely, the regulative approach could even support the creation of new business models, but most likely in a certain direction chosen by the regulating actor. This in itself is an obstacle to really new and innovative solutions. These aspects were partly analysed in Article I, where the heat trading concept of small scaled heat producers being able to sell their excess heat to the district heating network was analysed.

In regard to zoning more mixed zoning would be positive while that supports the development of more daily services available and workplaces being closer to residential areas. It could be stated in the regulations that the number of workplaces should be a certain minimum percentage of the number of residents estimated in the district. This raises the question about how to define a "workplace"? If the plan includes offices meant for remote workers, are these considered to be workplaces even if there is no guarantee of the plan being implemented? There is a risk of such lots being left empty, which does not serve anybody and only makes energy efficiency worse due to less density in the plan. On the master plan level, some zoning of activities enabling workplaces should at least be targeted. The details are moved on to the next planning phase, the detailed planning. The impact of workplaces and daily services on a districts energy efficiency were analysed in Articles II and V. In Article II, an energy efficiency rating tool is described and in Article V, a criteria setting for EcoCities in St Petersburg, Russia is analysed.

6.3 Detailed planning phase

In the detailed planning phase, the detailed energy use of the buildings can to some extent be influenced and some measures can be taken to enhance energy efficiency in living habits. In Finland, ways of regulating such choices are rather limited. The city plan can today enable renewable electricity production but cannot enforce it. Ways for enabling it are, for example, to direct houses optimally in regard to the solar energy production potential, i.e. roofs tilted towards the south with an optimal angle. In addition, the shading of the roof surfaces from other buildings and trees can be minimised. Small-scale 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. By an efficient placement of the lots and the buildings on the lots, transmission losses of district heating can be reduced. All these actions are, however, voluntary for the city planners. There could be regulations stating that the planners must take these aspects into account, that they must enable renewable energy. This would, however, require support for the city planners in terms of tools, guidelines and a closer collaboration with energy utilities. With tools like the one shown in Article II, a tighter regulation could be steered towards more energy efficient solutions.

Taking the regulation to a level where it would be strictly regulated to choose certain energy systems might not be wise. Innovative solutions might not be found if the choice of energy systems is regulated too much. There is also a risk of such a regulation being heavily influenced by politics, ending up with regulations supporting non optimal solutions. Another thing to remember is that there is no single optimal solution, but the optimum is always dependent on the location, the buildings and the available resources. Article IV, which analysed energy system renovations in districts in Moscow, concluded that analysis of emissions and impacts of different energy solutions is not straightforward and simple, but analyses must take different impacts into account and make an overall assessment based on local preferences. Therefore, it would not be possible to regulate the choice of a specific system. However, it should be regulated that options need to be analysed and that sustainability should be taken into account when choosing energy solutions.

The density level of the urban structure can influence the energy-efficiency of a district as was found in Article II where an energy efficiency rating tool was described. Dense city structure is considered an indicator of good planning, leading to higher energy efficiency and sustainability due to services being close and public transportation systems being profitable and well working. An interesting aspect in this regard is whether there is a limit to how dense the urban structure can get before the quality of life starts to decrease. Or will the decrease in quality of life happen only if the densification has not evolved in a regulated manner as is the case in Alexandria, Egypt. The urban structure is very dense, which should mean very well-functioning public transportation, but due to a very low level of regulations or enforcement of regulation, the end result is poor in terms of mobility and air quality. When applied to a well regulated environment, is there a point of density where the eco-efficiency starts to decrease?

6.4 Construction, usage and renovation phase

In the construction phase, the inspection of construction can take an active part in promoting renewable energy technologies and energy-efficient construction technologies. In order for the city planner and the inspection of construction to enable as much as possible and support the individual builders, they need to know what to promote. The questionnaire done for urban planners and construction inspectors showed a lack of knowhow and need for tools and support. When having easy-to-use tools that show what kind of energy solutions would lead to the overall most energy efficient solutions, they can take those solutions into account in their work. How much the construction inspectors can influence energy efficiency is today dependent only on the activity of the inspectors. The city can be active and train the inspectors to promote energy efficiency. The City of Oulu in Finland has for many years been an example of a city in which the building inspection has been promoting energy efficiency very actively. Some other cities have followed this example, but the majority of cities still much to improve in this respect. It could easily be regulated for cities to follow the example of Oulu. It should, however, be noted that cities have been given increasingly more tasks by the state with less and less money to carry out the tasks. It needs to be shown that the city will gain from the development and that it does not require much investment in terms of time and money. This is the case especially for smaller cities.

When considering the energy efficiency of districts, emphasis is also needed to be placed on increasing people's awareness of their living habits and their impact on energy efficiency. These are, however, things that are not very easily achieved through the city planning. Availability of daily services and public transportation are the obvious issues that can be influenced as discussed in Articles II and V. In Article II, an energy efficiency rating tool is described and in Article V, a criteria setting for EcoCities in St Petersburg, Russia is analysed. Domestic electricity use is more difficult to influence. The city plan can encourage people to install smart electricity meter devices that, in turn, enable a better awareness of electricity use. The utility company can, based on the real time energy data, provide different services to the consumers supporting more energy-aware habits.

Also, renovation activities need to be considered when discussing energy-efficient districts and city planning. As is clear, the pre-existing buildings consume most of the energy used by the built environment. There is a huge building stock reaching a state when major renovations are needed. Nowadays, renovations are most often done individually for each building, and its more seldom that a holistic approach is used where whole districts are considered and where energy efficiency improvement is not a key factor in the renovations. By planning renovations holistically and also taking the energy systems into account a better end result would often be achieved as was concluded in Articles III and IV where analyses of district level renovation concepts developed for conditions in Moscow, Russia, were performed with focus on energy efficiency and emissions. The challenge in such major renovation project is to get the different stakeholders to work together and to divide the costs and benefits among the stakeholders. The city planning could be the right actor to facilitate and promote such a process.

Table 6. Summary of findings, with a Finnish perspective.

Phase	Energy efficiency affected by	Current state	Suggested actions	Stakeholders	Foreseen impact
Regional planning	General objectives. Regional infrastructure.	Energy efficiency is often taken into account in general objectives. Energy efficiency impact of regional infrastructure decisions often unclear.	Create guidelines and tools for assessing different options impact on energy efficiency and sustainability. Legislation more detailed leaning on the use of agreed tools.	Ministries. Regional council.	Big impact, especially in terms of mobility.
Master planning	Zoning. Cities internal infrastructure.	Mixed zoning only rarely. Amount of workplaces and residents only seldom in balance. Transportation planning often primarily based on private cars (much dependent on location).	As above + More mixed zoning enabling services near residents. Holistic planning of energy systems on a city scale. Demand minimum number of workplaces near residential areas.	City planners. Energy companies. Service providers. Local politicians. Inhabitants.	Very big impact. Possibility to influence the whole citys energy efficiency.
Detailed city planning	Buildings energy efficiency, local energy systems, implementation of infrastructure.	Energy efficiency of buildings seldom considered. Seldom done energy analyses of the plans. In some cases district heating is enforced. When so, unclearly defined exceptions allowed. Seldom renewable building specific renewable energy is promoted.	Regulation for assessing the energy efficiency of detailed plans, to always promote renewable energy sources. Regulations for the orientation of buildings and design of roofs to be planned considering optimal solar energy utilisation. Public transportation and pedestrian and bicycle solutions should be considered as first options whenever feasible.	City planners. Energy companies. Service providers. Local politicians. Inhabitants.	Energy efficiency can be highly improved especially regarding maximising renewable energy sources. Impact on mobility less, more impacted of the master planning phase.
Construction	Quality of building inspectors. Enforcment of plans and regulations.	Building regulations are followed. Better solutions than what is demand is seldom built. How actively building instructions supports is highly dependent on the city.	Regulation to have all cities to follow the lessons learned from active cities, like the city of Oulu. Tools and guideines are needed for the building inspectors for actively pushing for energy efficient buildings and local renewable energy production.	Building inspectors. Constuction companies. HVAC technology and service providers. Inhabitants and other users. Local politicians. City planners.	Impact of this pahse dependent on the previous phase. If plan is non-regulativ, the construction phase can influence a lot the end result if builders are supported to build better than what is regulated.
Usage	User behaviour	Awareness about energy effiency slowly raising. Obstacle often that inhabitants dont have enough real-time knowledge about their energy usage.	Active promotion and development of services connected to smart meters. Energy efficiency awareness campaigns. Taxation based on energy efficiency.	Inhabitants and other users of buildings. Local politicians. City planners.	Usage phase has a very high impact on energy efficiency but regulative measures impact might be moderate only.
Renovation	Energy efficient renovations, holistic approach.	Renovation activities done case by case. Technical reasons base for renovations. Energy efficiency aspects taken into account in some cases in renvoations, but not in a consistent way.	City planning and building inspectors to be involved in renovation processess from early stage. As objective to be set to examine the possibilities to perform a district scale renovation and to take whole energy chain into account in the planning.	Building inspectors. Constuction companies. HVAC technology and service providers. Inhabitants. Local politicians. City planners.	Very high impact. Energy effiency and indoor quality can be enormously improved.

6.5 The role and importance of regulations

Highly regulated energy markets can be both a positive and a negative thing in terms of development. Low regulations have a positive impact on market forces. Enabling free business within energy market can have a positive effect on the implementation on renewable decentralised energy systems and other sustainable solutions. However, a regulative approach is beneficial when long-term solutions are sought, that does not bring short-term economic benefits, but serves society well in a longer time perspective. The challenge is to have regulation on a level that both steers the development towards the overall optimised solutions without hindering new innovative solutions from being found.

One development that has been slowed down because of a highly monopolised market is the heat trading concept that was analysed in Article I. The concept would allow small-scale heat producers to use the district heating network to sell their excess heat. The concept has not developed very quickly, one reason being that the district heating market is quite regulated and investment-intensive, most often dominated by one single actor on a local level. The energy companies have not seen as being to their benefit to allow small producers to use their networks to do business of their own. However, the concept enables a more efficient use of the building-scale production units and, when used on a wider scale, can have an impact on the sizing of the centralised heat producing units, which would also benefit the energy companies. Micro CHP units and solar heat are the most probable heating units that face the situation of excess heat production. In recent times, there have been some positive signals of the concept being slowly accepted, and we might see this succeeding in the future.

The key to developing sustainable city plans is for different disciplines to work closely together throughout the whole planning process. Transportation planning, planning of buildings and planning of energy systems needs to be done in a holistic way, working together. This is not to ignore water and waste management planning, which are not in the scope of this thesis. One example is a district level energy production system, such as a small-scale CHP plant. It requires a lot assigned to energy production and possibly needs storage spaces for fuel. In this example, a close collaboration between the city planning and the local energy utility makes sure that these are being taken into account in the plan. Proper tools are needed to allow the choices made to be holistically the most optimal. Otherwise, there is a risk of the decisions being made only being good for the energy utility and not for society as a whole and the people living there.

One important aspect when discussing regulative issues is the enforcement of the regulations. It is not enough to create good city plans and building regulations if there is no system that makes sure the plans are followed. In Alexandria, Egypt, the regulations and city plans are not followed fully, and there are seldom any sanctions for this. The result is a city where there are many buildings that do not officially exist, where no regulations have been followed. The quality of these buildings is often very poor and some buildings have even collapsed. Another end result of this is that the transportation system in the city has not been following the heavily increase of inhabitants. The public transportation system cannot cover the demand, and there is not enough room for the cars on the streets. The individual building owners have naturally not been able to see the holistic impacts of their individual actions; they have acted according to what is best for them on a short-term perspective. This is the way people tend to act when there is no societal pressure to steer them into acting in ways that is good for society as a whole.

To involve inhabitants and other stakeholders more in the city planning process has been an objective in the Finnish city planning process for some time now. New methods are continuously sought for engaging different stakeholders including residents as much as possible throughout the planning process. This is a good development which leads to both a higher acceptance of the plans, which in turns allows the plans to be more regulative. People tend to accept regulations and rules if they have been involved in their development. Also, for the purpose of engaging people in the planning process, tools can be of great value. To be able to show the energy efficiency impact of different planning solutions gives a much stronger base for the discussions than the aspects only being addressed in general terms.

When proposing a higher level of regulation to enhance a more energy-efficient built environment some caution needs to be taken due to the political factor. There is a risk that such regulations might not in the end be striving for the best technical solutions, but for the solutions that are considered the best politically. In this respect, there might be lots of lobbying from different sectors that are in a competing situation. This might be the case with different energy system solutions. The case with the primary energy factors used in calculating the E-numbers of the buildings is an example of this. The factors do not show the technically correct primary energy usage. It is an end result of lobbying and political compromises.

6.6 Further research

This thesis addresses only the energy efficiency of the built environment. It is clear that the scope needs to be extended to cover the sustainability of the built environment. It is of the greatest importance to include economic aspects in order to create solutions and processes that are realisable. How to weigh individuals' economic interests and the economic interests of society and how to weigh short-term and long-term economic implications are challenging issues to consider in developing any regulations impacting planning.

Social well-being is the third main aspect besides environmental and economic ones that need to be addressed when enlarging the scope from energy efficiency to sustainability. In general, it is likely that an increased level of regulation would reduce social well-being due to fewer possibilities of affecting choices related to people's own houses and ways of living. On the other hand, if social aspects are taken into account well when setting the regulative boundaries, this might be overcome, and we might end up with solutions that increase social well-being compared to the situation today. This would require that the supportive tools take into account all three corner stones of sustainability in the assessment of different solutions. In that way, the planners could regulate solutions that are sustainable overall. It is challenging to include social aspects into such tools, since those factors are difficult to turn into numbers. This is a topic where a great deal of further research is still needed.

A broader internationalisation of the results would be of benefit. Urban planning processes differ from country to country. A general guideline that could be easily adapted to local conditions could be of great benefit to achieve a wider impact of the results. The local conditions also differ in terms of the existing energy infrastructure. Whether there exist district heating networks or gas networks impact the possible energy solutions at hand. Also the primary energy factors of the district heating and electricity are local factors to take into account. An analysis of how these factors impact the overall energy efficiency and optimal energy solutions would be beneficial.

Primary energy factors used in this research are the ones that in Finland have been politically chosen to be used within the energy rating system. These are a mix of actual primary energy factors and a lobbying process from different interest groups. I would be of great benefit to decision makers if it could be shown how the factors impact the overall energy efficiency of districts. A sensitivity analysis showing the overall energy efficiency of districts with differing primary energy factors would give input to this discussion.

7. Conclusions

The topic of energy efficiency in city planning can be divided into three main areas: the urban planning process, transportation solutions and energy systems covering demand, the transmission and production of energy. The field is broad and the challenge is to combine the different aspects into a holistic approach.

The objective of this thesis was to analyse the role and impact of regulation in the development of energy efficient districts.

The journal articles (Articles I–IV) concluded the following:

- A holistic approach and enabling new heat trading models in district heating systems enable a district's self-sufficiency in terms of energy. These support more sustainable energy solutions in districts. (Article I.)

- Tools to assess energy efficiency of districts enable city planners to easily compare detailed city plans. This enables energy-efficient solutions to be selected if a regulative approach is chosen. (Article II.)

- To achieve a universally efficient energy solution, the entire energy chain needs to be analysed and improvements made, bearing in mind the whole energy chain. Such analyses can only be done with a top-down approach. (Article III.)

- The interpretation of the analysis of emissions of different energy choices can be complex. In order for a city planner to assess these impacts, supportive tools and guidelines are needed. It was also shown that quality of life is often improved through large renovation activities, which often cannot be performed without a regulative holistic approach due to the economic constraints of individual apartment owners. (Article IV.)

For city planners to be able to take holistically sustainable decisions, support is needed. The challenge of combining different disciplines into a holistic approach leads to the need for both easy-to-use tools, guidelines and above all a planning process that brings the different disciplines together. Without a holistic approach, the end result is easily a sub-optimised solution.

It is important to understand the different planning phases and what decisions are made at which stage. The impacts of decisions made in the different planning phase are important to show to decision makers. Also, it is important to understand how the decisions taken in one planning phase influences the following planning level and this needs to be clearly shown to decision makers. Today, there is a lot to be improved in this respect.

Based on findings in Articles II, III, IV and V, it can be concluded that there are many ways for the city planners to take energy-efficiency into account and to enable renewable energy sources and sustainable transportation solutions. However, all these measures are today voluntary for the city planners. There is no obligation for them to do their best in achieving energy-efficient city plans.

It is recommended that the city planning process should be regulated to demand that city planners and energy systems planners address energy efficiency by the following means:

- Mixed zoning should always be considered. It should be stated in the regulations that the number of workplaces should be a certain minimum percentage of the number of residents estimated in the district. Also different residential housing types rather than the typical one family house districts should be considered in order to achieve higher density. The tool described in Article II shows the impact of workplaces on the districts energy efficiency.

- The energy efficiency of a city plan should always have to be assessed, and the efficiency classes of different planning options should be disseminated to decision makers and other stakeholders before approving the plan.

- In urban settlements, it should be obligatory to include in the city plan daily services at a walking distance from residential buildings. If this is not economically feasible, it should be ensured that public transportation is available for reaching the services. The availability should include a good level of service of the public transportation system. The tool described in Article II shows the impact of daily services on the districts energy efficiency.

- Transportation should always be planned with public transport and cycle and pedestrian routes as first preference. Centralised parking outside of a residential district should be considered. The availability of charging poles for electrical cars should be included in the centralised parking places. Parking place costs should not be allowed to be included in the price of apartments or houses, but should be always an extra cost paid only by those who use the parking place service. With the tool described in Article II, parking solutions impact on a districts overall energy efficiency can be assessed. As discussed in Article V, transportation solutions are key factors in an EcoCity concept.

- When placing buildings and setting boundaries for the roofs, in the detailed planning phase, maximum solar utilisation should always be considered. It should be noted that this planning should be done together with planning the whole energy system in the district. If the district has a common energy distribution system, an overall optimal solution might be achieved by placing some buildings towards the east, some towards the south and some towards the west, in order to achieve an overall maximum solar utilisation. Such solutions can only be found if the system is planned holistically as in the next bullet point.

- Energy systems should always be considered holistically in the master plan phase as well as in the detailed planning phase. The aim should be to analyse which energy system is the most feasible in the specific location. A close collaboration between the energy utility and the city planners should be obligatory.

- The municipalities building instructors should be obliged to follow the example of the City of Oulu, increase their knowhow and take an active approach in supporting builders to achieve better energy efficiency. A national education module should be developed and carried out for this important group of experts. The questionnaire showed a need for further support for this group.

- As discussed in Articles III and IV, the municipality should have a coordinating and leading role in any major renovation actions (meaning more than a single family home renovation project) to enable a holistic approach in the renovation enabling energy efficiency improvement potential to be realised. The energy utility should be involved in this process as well.

To conclude, it should be noted that, even though the recommendations listed above might feel too regulative and like reducing the individual's right to live their lives as they please, their overall aim is to increase the quality of life and to increase the welfare of society as a whole. Allowing stakeholders to plan solutions based only on their own interests leads to sub-optimised solutions. Energy-efficiency is a multidimensional issue which can seldom be achieved by such sub-optimised solutions. Our society is facing such tough times in terms of energy usage and emissions that a stricter more regulative approach to planning is needed.

Acknowledgements

This research has been done within different national and international research, development, and innovation projects. The work in Article I concerning heat trading was done within a project Hetra funded by Tekes and VTT. The work in Article II where a tool for assessing energy efficiency in detailed city plans is described, was done partly in the project Ekotaajama funded by Sitra, Tekes and the Finnish cities Jyväskylä, Toivakka, Multia, Petäjävesi, Jämsä and Kannonkoski and partly within the Ensio project funded by VTT. Articles III and IV that analyse renovation concepts in Moscow, Russia, were done within the ModernMoscow project funded by the Ministry for Foreign Affairs of Finland, that also funded the project EcoGrad within which the conference paper (Article V) was done. In addition to the work done with writing the articles, VTT Technical Research Centre of Finland Ltd has funded one month of worktime for summarising the findings into this thesis. My deepest gratitude to all listed above, especially to VTT for supporting this research work.

References

Annunziata, E., Frey, M. & Rizzi, F. 2013. Towards nearly zero-energy buildings: The state of the art of national regulations in Europe. Energy (57), 125–133.

Atkisson, A. & Hatcher, L.R. 2001. The Compass Index of Sustainability: Prototype for a Comprehensive Sustainability Information System. Journal of Environmental Assessment, Policy and Management (JEAPM), Vol. 3, No. 4, December 2001.

Bindra, S. & Giel, D. 2006. Tran T. Smart Transportation Planning in Freiburg, Germany. 2006. Available (20.12.2012): http://www.engr.uconn.edu/~garrick/ce255/2006/Freiburg.pdf

BREEAM. 2012. BREEAM Communities – Technical Manual. SD202 – 0.0.2012. BRE Global Ltd. Available: http://www.breeam.org/communitiesmanual/.

Brundell-Freij, K. & Ericsson, E. 2013. Klimat 2030 – Planeringsåtgärder för minskat bilresande I städer. – Krav på åtgärdsomfattning för uppnåended av klimatmålen. [Online] (Referred to 6.10.2014): http://www.wspgroup.com/upload/documents/Sweden/analys/Rapporter/Rapporter%202012/Rapport_Klimatscenario_final.pdf

Business dictionary. 2012. http://www.businessdictionary.com/definition/quality-of-life.html

CASBEE. 2007. CASBEE for Urban Development – Technical Manual 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 Consortium (JSBC).

Chittum, A. & Østergaard, P.A. 2014. How Danish communal heat planning empowers municipalities and benefits individual consumers. Energy Policy (74), 465–474.

Costanza, R. & Patten, B.C. 1995. Defining and predicting sustainability. Ecological Economics (15), 193–196.

Dentice d'Accadia, M., Sasso, M., Sibilio, S. & Vanoli, L. 2003. Micro-combined heat and power in residential and light commercial applications. Applied Thermal Engineering (23), 1247–1259.

DeSimone, L.D. & Popoff, F. 2000. Eco-efficiency: the business link to sustainable development. Cambridge, MA, USA: MIT Press. ISBN: 0-262-04162-6.

Dreher, A., Kostogiannis, C. & McCorriston, S. 2007. Corruption around the world: Evidence from a structural model. Journal of Comparative Economics (35), 443–466.

Eleftheriadis, I. & Anagnostopoulou, E. 2015. Identifying barriers in the diffusion of renewable energy sources. Energy Policy (80), 153–164.

Eliseev, K. 2011. District heating systems in Finland and Russia. Mikkeli University of Applied Science. Bachelor's thesis. 39 p. (Accessed 8.1.13: http://publications.theseus.fi/bitstream/handle/10024/25777/DISTRICTHEATING SYSTEMS IN FINLAND AND RUSSIA.pdf?sequence=1)

European Parliament. 2002. Directive 2002/91/CE of the European Parliament and of the Council of 6 December 2002 on the energy performance of buildings. Bruxelles (2002) Available from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002L0091:en:HTML

European Parliament. 2010. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Bruxelles (2010) Available from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ: L:2010:153:0013:0035:EN: PDF

Finlex. 1999. 132/1999. Maankäyttö- ja rakennuslaki. [Online article.] (Referred at 28.1.2012.) Available at: http://www.finlex.fi.

Finnish Energy Industries. 2009. District heating energy statistics from 2009. Available (12.12.2012): http://energia.fi/tilastot-ja-julkaisut/kaukolampotilastot (in Finnish)

GEMIS Manual. Referred 15.10.2010. http://www.oeko.de/service/gemis/files/doku/g45_manual.pdf

Haapio, A. 2012. Towards sustainable urban communities. Environmental Impact Assessment Review (32) 165–169.

Hamers, D., Snellen, D., Breedijk, M., Hilbers, H., Nabielek, K., Tennekes, J., van Amsterdam, vH., Bregt, A., Evers, D., van Meerkerk, J. & Ritsema van Eck, J. 2014. Kiezen én delen. Strategieën voor een betere afstemming tussen verstedelijking en infrastructuur. ISBN: 978-94-91506-79-6. Available Online (accessed 2.12.2014): http://www.pbl.nl/sites/default/files/cms/publicaties/PBL_2014_Kiezen%20%C3%A9n%20delen_1358.pdf

Hoang, H. 2012. How urban planning could better contribute to opportunities for utilizing solar energy in Finland. Master's thesis. Aalto University, School of Engineering. 100 p.

IEA. 2008. Electricity/Heat in Russia Federation in 2008. Referred 2.9.2010. Available: http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=RU

IPCC. 2007. Summary for policymakers: Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press.

Johansson, H., Eklöf, H. & Karlsson, L. 2010. Trafikverket. Trafikslagsövergripande planeringsunderlag för begränsad klimatpåverkan. ISBN 978-91-7467-069-1.

Jyväskylä Innovation. 2012. Ekotaajma Project Results. (In Finnish.) Available (7.12.2012): http://www.jklinnovation.fi/default/www/jyvaskyla_innovation_oy/osaamiskeskusohjelma/energiateknologia/projektit/

Kosonen, R. & Shemeikka, J. 1997. The use of a simple simulation tool for energy analysis. IBPSA Proceedings. Available online (22.4.2015): http://www.ibpsa.org/%5Cproceedings%5CBS1997%5CBS97_P103.pdf

Kuik, O. & Osterhuis, F. 2008. Policy instruments for environmental innovations, presented at the DIME workshop "Empirical analyses of environmental innovation". Fraunhofer ISI, Karlsruhe.

Kuntaliitto. 2013. Association of Finnish Local and Regional Authorities. Available online: http://www.kunnat.net/fi/kunnat/toiminta/perustiedot/Sivut/default.aspx Referred to 17.9.2013.

Lahti, P., Calderón, E., Jones, P., Rijsberman, M. & Stuip, J. 2007. Towards Sustainable Urban Infrastructure. Assessment, Tools and Good Practice. European Science Foundation ESF/COST Publication. Helsinki. 336 p. ISBN 978-92-898-0035-8.

LEED. 2011. Homepage of LEED [webpage] http://www.usgbc.org/DisplayPage.aspx?CMSPageID=148. Accessed Nov 2012.

Lund, H. 2010. The implementation of renewable energy systems. Lessons learned from the Danish case. Energy (35), 4003–4009.

Lund, H. & Kempton, W. 2008. Integration of renewable energy into the transport and electricity sectors through V2G. Energy Policy (36), 3578–3587.

McCarthy, S., James, P. & Bayliss, C. 2010. Sustainable Cities, Vol. 1. United Nations Global Compact, Cities Programme, New York and Melbourne.

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. 2012. D3 Energy management in buildings Regulations and guidelines 2012. Available at: http://www.finlex.fi/data/normit/37188-D3-2012_Suomi.pdf (in Finnish).

Nieminen, J. & Lylykangas, K. 2009. Passiivitalon määritelmä. Ohjeita passiivitalon arkkitehtisuunnitteluun. Referred 10.12.2010. Available: http://www.passiivi.info/download/passiivitalon_maaritelma.pdf

Nikkanen, A. & Lahti, P. 2011. It takes only two hours to get rough estimate of urban eco-efficiency. World Sustainable Building Conference, Helsinki.

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 Research Notes 2566. Espoo: VTT. 75 p. + app. 12 p. ISBN 978-951-38-7701-9. http://www.vtt.fi/inf/pdf/tiedotteet/2010/T2566.pdf

Opitz, M.W., Norford, L.K. Matrosov, Y.A. & Butovsky, I.N. 1997. Energy consumption and conservation in the Russian apartment building stock. Energy and Buildings (25), 75–92.

Ouyang, J., Ge, J., Shen, T., Hokao, K. & Gaor, J. 2008. 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), 139–146. ISSN 1346-7581.

Paiho, S. 2014. Energy-efficient renovation of residential districts. Cases from the Russian market. VTT Science 72. Espoo: VTT. www.vtt.fi/inf/pdf/science/2014/S72.pdf. ISBN 978-951-38-8187-0.

Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. 2007. World population prospects: the 2006 revision and world urbanisation prospects: the 2007 revision.

Rajala, P., Hirvonen, H., Perttula, S., Lähde, E., Pulkka, P., Jarmala, L., Laukkanen, J., Patronen, J., Jokinen, M., Rintala, T., Rajakallio, K. & Kauppinen, T. 2010. Energiatehokkuus kaavoituksessa. Publication of Sitra. Helsinki: Sitra. ISBN 978-951-563-742-0. http://www.sitra.fi

Roseland, M. 1997. Dimensions of the eco-city. Cities (14), 197–202.

Roseland, M. 2000. Sustainable community development: integrating environmental, economic, and social objectives. Progress in Planning (45), 73–132.

Serag El Din, H., Shalaby, A., Farouh, H. & Elariane, S. 2013. Principles of urban quality of life for a neighbourhood. HBRC Journal (9), 86–92.

Shahin, M. 2001. Energy Conservation in Urban Areas in the Framework of a Sustainable Transportation Concept. Hannover Univ. (Germany). Inst. fuer Verkehrswirtschaft, Strassenwesen und Staedtebau. Available online: http://hdl.handle.net/10068/159964

Sipilä, K., Ikäheimo, J., Forsström, J., Shemeikka, J., Klobut, K., Nystedt, Å. & Jahn, J. 2005. Technical features for heat trade in distributed energy generation. VTT Tiedotteita – Research Notes 2305. Espoo: VTT. 111 p. http://www.vtt.fi/inf/pdf/tiedotteet/2005/T2305.pdf

SP Elements. 2010. Hallipeli – Hallin rakentamisen kustannusarvio. Available (1.2.2011) at: http://www.hallipeli.fi

Statistics Finland. 2011. Appendix figure 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 (referred to 17.9.2013)

Strom, I., Joosten, L., Boonstra., Nieminen, J., Saari, M. & Nykänen, E. 2006. Työraportti 1.2 Passiivisen talon ratkaisut. Work report of Promotion of European Passive Houses project. Referred 10.12.2010. Available: http://erg.ucd.ie/pep/pdf/Passive_House_Sol_Finnish.pdf

Sundström, A. 2015. Covenants with broken swords: Corruption and law enforcement in governance of the commons. Global Environmental Change (31), 253–262.

Tol, H.I. & Svendsen, S. 2012. A comparative study on substation types and network layouts in connection with low-energy district heating systems. Enery Conversion and Management (64), 551–561.

Trafikverket. 2012. Målbild för ett transportsystem som uppfyller klimatmål och vägen dit. [Online] (referred to 6.10.2014): http://publikationswebbutik.vv.se/upload/6686/2012_105_malbild_for_ett_transportsystem_som_uppfyller_klimatmal_och_vagen_dit_2.pdf

Tuominen, P., Forsström, J. & Honkatukia, J. 2013. Economic effects of energy efficiency improvements in the Finnish building stock. Energy Policy (52), 181–189.

UN. 1987. Report of the world commission on environment and development: our common future. New York: United Nations General Assembly. Available online: http://www.un-documents.net/wced-ocf.htm

Ürge-Vorsatz, D., Koeppel, S. & Mirasgedis, S. 2007. Appraisal of policy instruments for reducing building's CO_2 emissions. Building Research and Information (35), 458–477.

Virkki-Hatakka, T., Luoranen, M. & Ikävalko, M. 2013. Differences in perception: How the experts look at energy efficiency (findings from a Finnish survey). Energy Policy (60), 499–508.

VTT. 2009. Energy Visions 2050. Espoo: VTT. ISBN 978-951-37-5595-9.

WBSCD. 2000. Eco-efficiency. Creating more value with less impact. Geneva: World Business Council for Sustainable Development.

Zyadin, A., Halder, P., Kähkönen, T. & Puhakka, A. 2014. Challenges to renewable energy: A bulletin of perceptions from international academic arena. Renewabel Energy (69), 82–88.

Appendix A: Articles I–V

ARTICLE I

Case analyses of heat trading between buildings connected by a district heating network

Energy Conversion and Management (47), 3652–3658.

Available online at www.sciencedirect.com
ScienceDirect
Energy Conversion and Management 47 (2006) 3652–3658
ENERGY CONVERSION & MANAGEMENT
www.elsevier.com/locate/enconman

Case analyses of heat trading between buildings connected by a district heating network

Å. Nystedt *, J. Shemeikka, K. Klobut

VTT Technical Research Centre of Finland, PO Box 1800, FI-02044 VTT Espoo, Finland

Available online 17 April 2006

Abstract

This study examined the decentralisation of energy production with possibilities of trading not only electricity but also heat. This was carried out with a limited population of buildings connected to the district heating network in a small town in Finland.

The study examined whether a buildings community could be self sufficient with respect to heat by using small CHP plants, and explored the consequences of such an energy system. It also aimed to find an optimal solution. Therefore, it searched in what type of buildings should the micro-CHP plants be installed and with what kind of strategy should they be operated in order for the community to be energetically self sufficient without producing lots of excess heat.

Keywords: Decentralised energy systems; Heat trading; Micro-CHP; Fuel cell

1. Introduction

In centralised energy systems electricity is produced in large power plants and delivered to the consumer through the grid. Combined heat and power generation (CHP) used in large power stations is a process where heat, generated as a side product of electricity production, is captured and delivered by means of district heating network to buildings.

Decentralisation of energy production means generation of energy close to, or at the consumption site. Distributed energy systems enable the use of a lighter infrastructure; the transfer capacity does not need to bear as high loads as with centralised energy production. This might lead to lower cost investments.

Decentralised power production has already reached the level of an individual building. We use the term "micro-CHP" when referring to a combined heat and power generation plant installed in a building. According to a recent study [1] fuel cells technology is one of the most interesting technologies for applications in CHP plants in buildings. Fuel cells can perform well at part load and can operate with different fuels, the most common being natural gas. While operating on pure hydrogen there are no polluting emissions at all.

* Corresponding author. Tel.: +358 20 722 4744; fax: +358 20 722 7054.
E-mail address: asa.nystedt@vtt.fi (Å. Nystedt).

0196-8904/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enconman.2006.02.030

However, according to a recent study [2] this is an expensive technology which is still in its developing phase. Market competitiveness of fuel cells could be improved when they are used in systems where there is energy trading.

Long lasting power blackouts have become more common, especially in the USA. It has been forecasted that these kinds of power blackouts will become more common in the future due to aged and overloaded transmission systems and an increase of electricity demand. Therefore, a vision of energetically self-sufficient buildings becomes more interesting with such forecasts. Using micro-CHP plants is one way of providing energetically self sufficient buildings.

When a micro-CHP plant produces electricity, it also produces heat that can be regarded as a "side-product". This heat can be used to cover the buildings heat demand. If more heat is produced than demanded, the excess heat could be sold to the district heating network. If more electricity is produced than demanded, it could also be sold to the electrical network. However, this study focuses on heat trading.

2. Methodology

A simple computer program was developed to calculate the heat and electricity demand and production for a group of buildings for each hour of the year. Seven different building types with different consumption profiles were included in the study (detached houses, terrace houses, apartment buildings, hospitals, educational buildings, offices, assembly buildings). For the residential and the office buildings, both new and old buildings were included in the study. Table 1 shows all the different types of building that were considered in the simulations.

The cases that have been studied are listed in Table 2. In this paper the letters of Table 2 will be used to describe the different cases.

There was a central CHP plant connected to the network and it was assumed that each building could be equipped with an individual micro-CHP plant, which provided heat (and electricity) to satisfy the demand of the building itself or was sold.

Table 1
Buildings of the case community considered in the simulations

Building type	m^3	% of total
Commercial building	5160	2
New office	17 320	7
Old office	20 780	9
Old apartment building	71 240	29
New apartment building	30 680	13
Hospital	5340	2
Educational building	7370	3
Assembly building	13 650	6
Old detached house	44 030	18
New detached house	18 870	8
Old terrace house	5200	2
New terrace house	2600	1

Table 2
Cases used in the study

A	100% degree of decentralisation
B	75% degree of decentralisation
C	50% degree of decentralisation
D	25% degree of decentralisation
E	"Optimal solution"
F	CHP in all except detached and terrace houses
G	CHP only in residential buildings
H	CHP only in residential buildings, constant production strategy

For the micro-CHP plants it was assumed that for each kW h of electricity produced, there were also 2 kW h of heat.

2.1. Cogeneration operating strategies

The following cogeneration strategies, based on a previous study [3], were considered:

- *Electrical load tracking strategy*: the micro-CHP plant has an electrical capacity that exceeds the minimum electrical requirement for the facility. The micro-CHP plant power output changes in response to the needs of the facility.
- *Thermal load tracking strategy*: the system is designed to follow the thermal load of the facility. The power generated during the supply of the thermal load is used to replace purchased electricity. The excess power can often be sold to the utility company.
- *Electrical base load strategy*: the micro-CHP plant is designed to supply the minimum amount of power required by the facility. Therefore, the micro-CHP plant can operate continuously at peak power output.
- *Thermal base load strategy*: the system is designed to meet the minimum thermal load. Thermal energy to meet peak loads is provided by an auxiliary heat source, such as a boiler. Power is purchased from or sold to the grid to balance the electricity demand of the facility with power supplied by a fuel cell system.

3. Results

The case town has both residential and non residential buildings. It is estimated that 70% of the residential buildings are old while 30% are new. The age of the buildings affects the energy demand curves. Simulations answered the question whether the town could be self-sufficient in terms of heat or electricity production. It also answered whether the community could sell some heat or electricity and whether it needed to buy from the centralised energy production.

At first, three cases – most relevant for this study – are presented in more detail. Subsequently, the other cases are included in comparison and discussion of annual results.

3.1. Case A: 100% decentralisation

As a base case, the degree of decentralisation was set to be 100%, which means that all the buildings have their own micro-CHP plants. The plants followed an electrical load tracking strategy. In this base case, the town was completely self-sufficient with respect to heat from June to September (see Fig. 1). During these

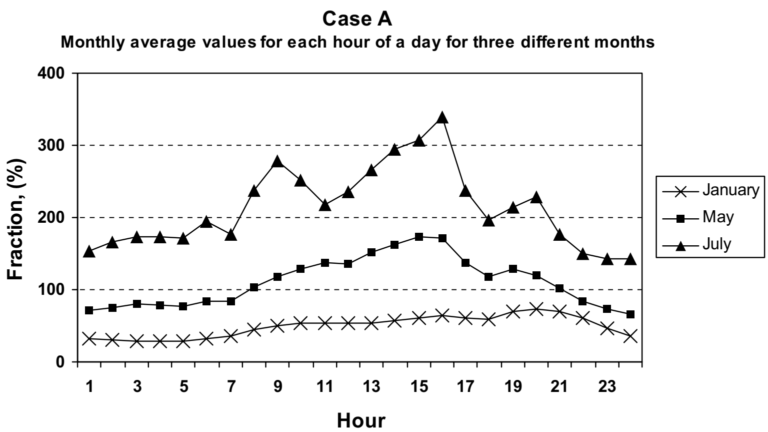


Fig. 1. Amount of decentralised heat production in Case A relative to heat demand.

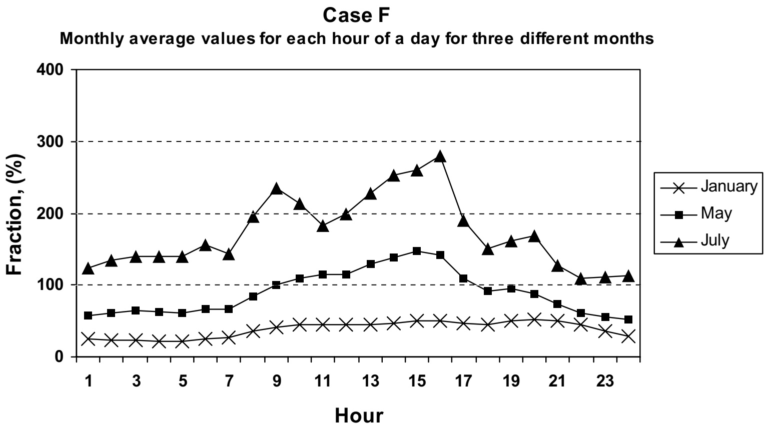


Fig. 2. Amount of decentralised heat production in Case F relative to heat demand.

months heat could be sold to the district heating network. Further analysis showed that when the degree of decentralisation was lower, the system naturally needed more heat from centralised production. The results are calculated as monthly average values for each hour during the day.

3.2. Case F: Decentralised production in other than small detached and terrace houses

Another case was when micro-CHP plants are installed in all building types except for small detached and terrace houses. This means that all of the buildings, except detached and terrace houses have a micro-CHP plant. The micro-CHP plants followed an electric load strategy. In this case the whole community is self-sufficient with respect to heat from June to September. The excess heat from the buildings which have a micro-CHP plant covers the heat demand of the small detached and terrace houses. During these months, there is excess heat production up to 250% of the total heat demand (see Fig. 2). Here, a question to consider is whether there is enough capacity in the district heating network for this excess heat production and whether there are buyers for this heat.

3.3. Case E: Optimal solution

An optimal solution was empirically searched for. By optimal we mean that the shared distributed energy production should be close to 100% at all times, i.e. centralised heat production would not be needed at all and the excess decentralised heat production would be zero. The community would, in other words, be self-sufficient and not have excess heat production. The closest we got to this optimal case was a solution where the share of distributed energy production varied between 55% and 200% of the total demand, the 200% being just a peak at around 16 h (see Fig. 3).

This solution was found by modifying Case F so as to allow different operation strategies for CHP plants in summer and in winter in all but the apartment houses. The seasonal switch changes were not made in the apartment buildings since it was assumed that they have more seldom professionals handling their technical service systems. In winter, the micro-CHP plants were set to constantly produce 125% of the maximum electricity demand, this figure being only 25% in summer. In the apartment buildings, the micro-CHP plants followed an electric load strategy all the time. In this case, considerable amount of electricity was being sold during winter, while in summer electricity was needed from the centralised unit. Since prices are higher in winter than in summer, this was advantageous for the producer.

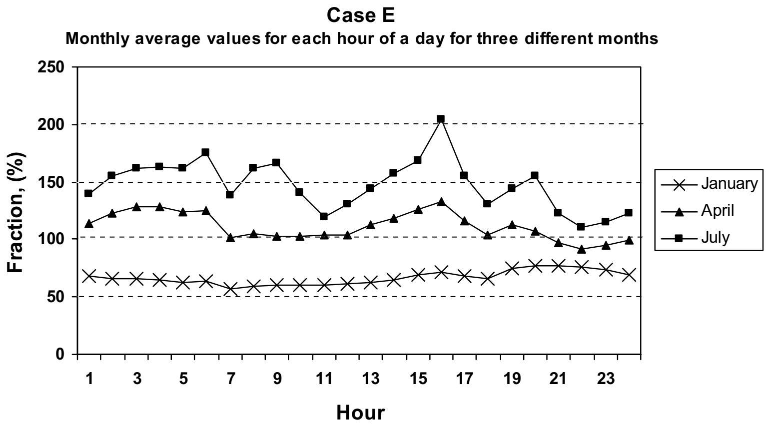


Fig. 3. Amount of decentralised heat production in Case E relative to heat demand.

3.4. Comparing different cases

Fig. 4 shows the need for centralised heat production for five different cases. Four cases had micro-CHP plants in all types of building, the first case having them in 100% of all buildings (case A), the second in 75% (case B), the third in 50% (case C) and the fourth in only 25% (case D). The fifth case is the "optimal solution" described earlier (case E). As can be seen, when the degree of decentralisation is lower than 50%, centralised heat production is needed even in summer months. In the optimal solutions curve it is clearly shown that the parameters for the micro-CHP plants are changed in May and September. In this case, the community produces some excessive heat during summer, early spring and late autumn. However, the excessive production is not as great as in the case of 100% decentralisation.

In Fig. 5, we see that the amount of heat needed from the centralised production varies between approximately 0.5 and 8.6 GW h/year, the total yearly heat demand of the community being 10.7 GW h. The worst case is with a decentralisation degree of only 25%. The best case is with micro-CHP plants in residential build-

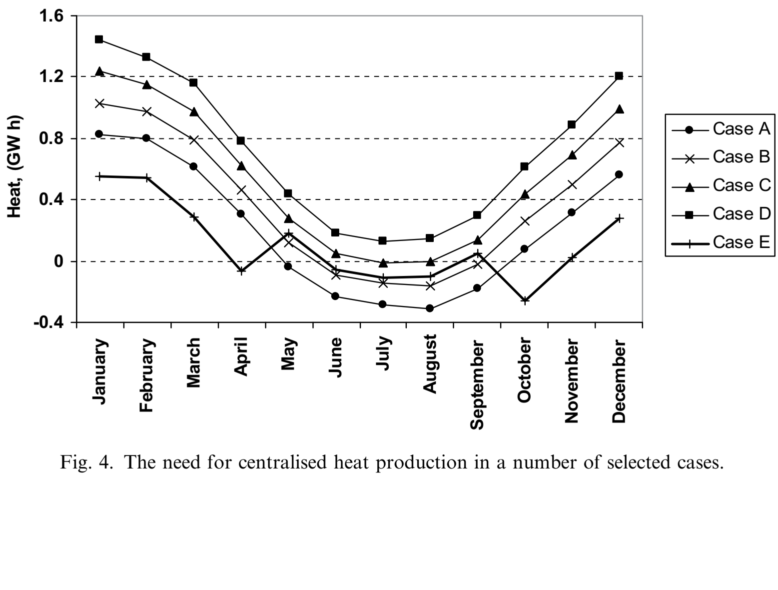


Fig. 4. The need for centralised heat production in a number of selected cases.

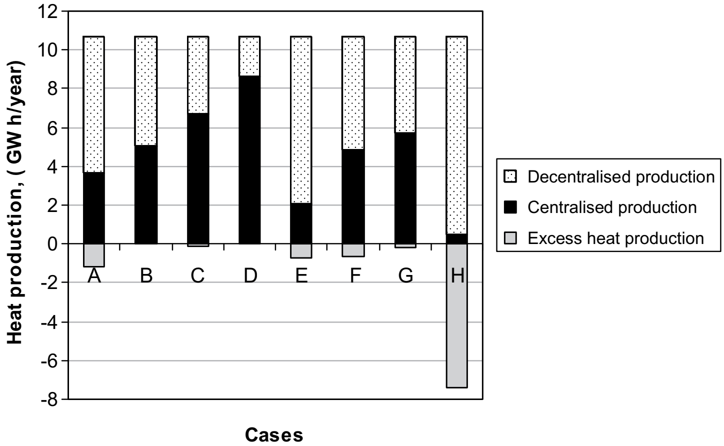


Fig. 5. Net heat from centralised production, decentralised production and excessive heat production in different cases.

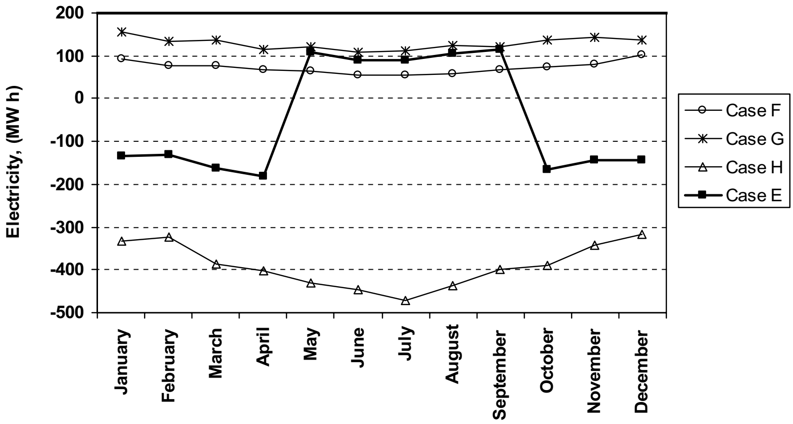


Fig. 6. Centralised electricity production for selected cases.

ings running with constant production. This case, however, produces a lot of excessive heat which the optimal case, case E does not as much.

Fig. 6 shows centralised electricity production for selected cases. When micro-CHP plants are installed only in residential buildings and operating with constant electricity production (case H), the community has a lot of excessive electricity production. When the case is the same but the plants have an electric load tracking strategy (case G) there is constantly a need for centralised electricity production. We get approximately the same result from the case where plants are installed in all other building types than detached and terrace houses (case F). In the ''optimal case'' (case E) there is excessive electricity production from October to April. In the summer centralised electricity production is needed. Since electricity prices tend to be higher in winter, when the overall demand is higher in Finland, it is good to sell electricity in winter and buy it in summer.

4. Discussion

Our limited simulations showed that heat trading could be a functional way to develop decentralised energy systems. There is a potential advantage when buildings, with consumption profiles that are different in shape and/or timing, are connected through a district heating network. However, it is unlikely that this potential could be utilised by simply providing a micro-CHP plant to every building. A holistic approach to dimensioning and control strategies in different buildings will be needed as well as a smart mix of buildings with and without CHP plants. A possibility to use thermally activated cooling in the district heating network could be considered as a supplementary measure for use of the excess heat in summer.

Theoretically, heat trading could be a functional way to improve the financial prospect of micro-CHP plants. Having a way to sell the excess heat production improves the cost-effectiveness. However, there are obstacles since the heat market is not yet a free market but is still a regulated one which is a major threshold for a functional heat trading.

The emissions trade would also apply to small producers since it is stated that if the network has a capacity higher than 20 MW all producers in the network are concerned by the emissions trading. This is a regulation meant to forbid centralised production to split up its units to avoid the emissions trade. By using fuel cells operating with hydrogen we do not need to be concerned about this since there are no CO_2 emissions. Having a plant with no CO_2 emissions also gives the opportunity to sell emissions quota. This is, however, one kind of a micro-CHP technology which has still many obstacles.

If heat trading would be a reality there would be a need for some party to manage the whole trading system. The energy companies seem naturally suited for this since they have the know-how about the district heating networks and their functionality. Today it seems as they see the heat trading concept as a competition to their business.

One serious possible obstacle for a widely spread heat trading is that micro-CHP plant often uses natural gas as a fuel, which means that it most often has to be connected to a natural gas network. At the same time, the building has to be connected to a district heating network in order to sell out its excessive heat. It is quite rare in Finland (but not e.g., in Central Europe) that we have both a natural gas network and a district heating network at the same location.

5. Conclusions

Our limited simulations showed that heat trading could be a functional way to develop decentralised energy systems. There is a potential advantage to be utilised when buildings, with consumption profiles different in shape and/or timing, are connected through a district heating network.

Economic aspects were left outside the scope of this study. This is an area where further research is needed in order to understand better the possibilities of heat trading. Technical demand on the district heating network is another aspect that has not yet been taken into account in the study. The promising perspectives of the heat trading concept will be further investigated in the near future.

Acknowledgements

This study has been financed by Tekes (National Technology Agency in Finland) and by VTT.

References

[1] Vartiainen E, Luoma P, Hiltunen J, Vanhanen J. Distributed energy production; technology, fuels, markets and CO_2 emissions. Helsinki: Gaia Group Ltd.; 2002, ISBN 952-91-4465-2 (In Finnish).

[2] Energy Nexus Group. Technology characterization: fuel cells. Report prepared for Environmental Protection Agency Climate Protection Partnership Division. Washington, DC, 2002.

[3] Ellis MW, Fuel cells for building applications, ASHRAE, 2002, ISBN 1-93186-03-6.

ARTICLE II

Energy efficiency rating of districts, case Finland

Energy Policy (65), 408–418.

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

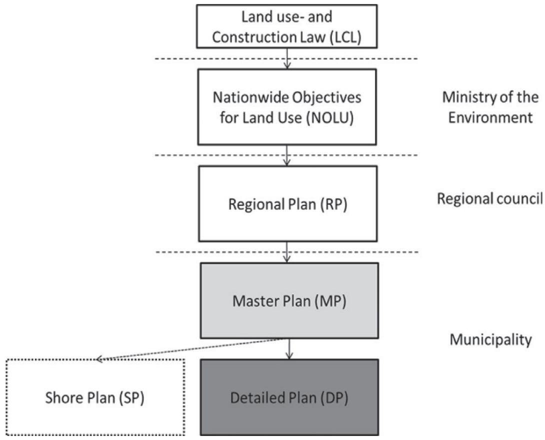


Fig. 1. The hierarchy chain of urban planning in Finland (FINLEX, 1999).

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 tool.

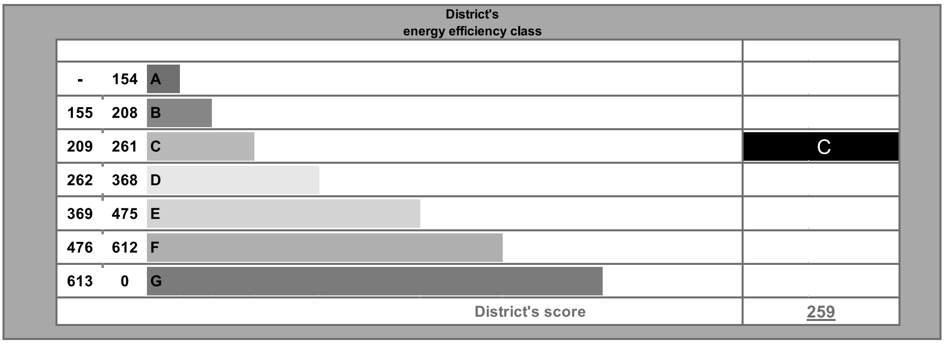


Fig. 3. The result diagram of the district energy rating tool.

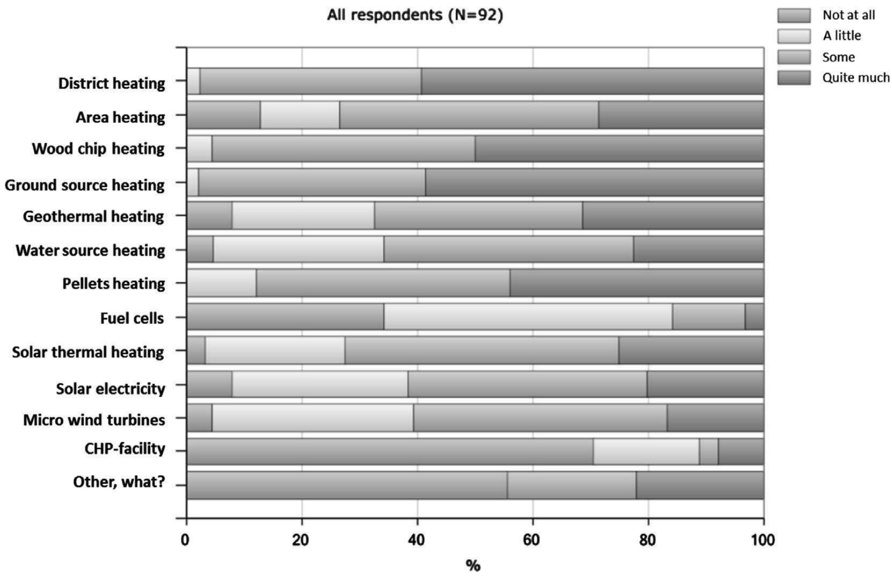


Fig. 4. Results of the questionnaires question "How familiar are the following energy systems?"

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

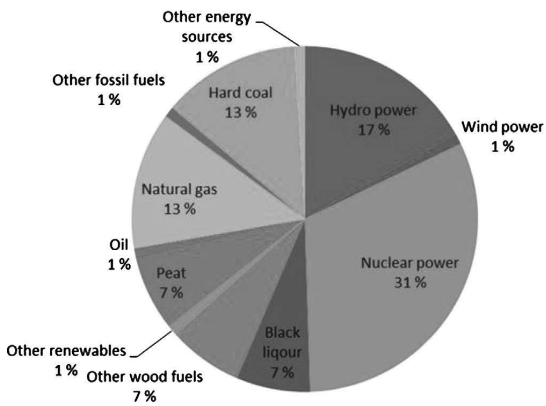


Fig. 5. The Finnish electricity production mix. Additional to this 13.9 TW h (16.5% of the total demand) was imported in 2011 (Satistics Finland, 2011).

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.

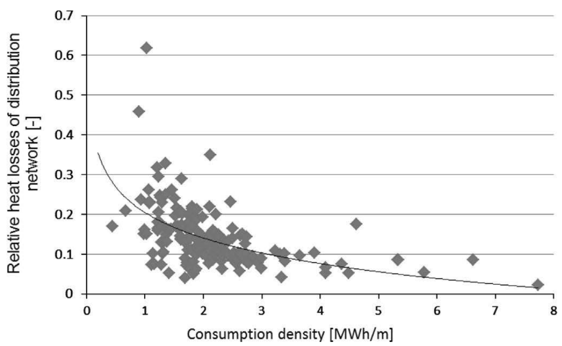


Fig. 6. The estimated ratio of the density of energy consumption and the relative heat distribution losses (which are relative to the total energy production) of district heating networks in Finnish cities (calculations based on data from Finnish Energy Industries (2009)).

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).

$$E - \text{number} = \frac{\Sigma_i (E_{\text{cons},i} - E_{prod,i}) f_i + E_{trans}}{A_{net}} \quad (1)$$

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.

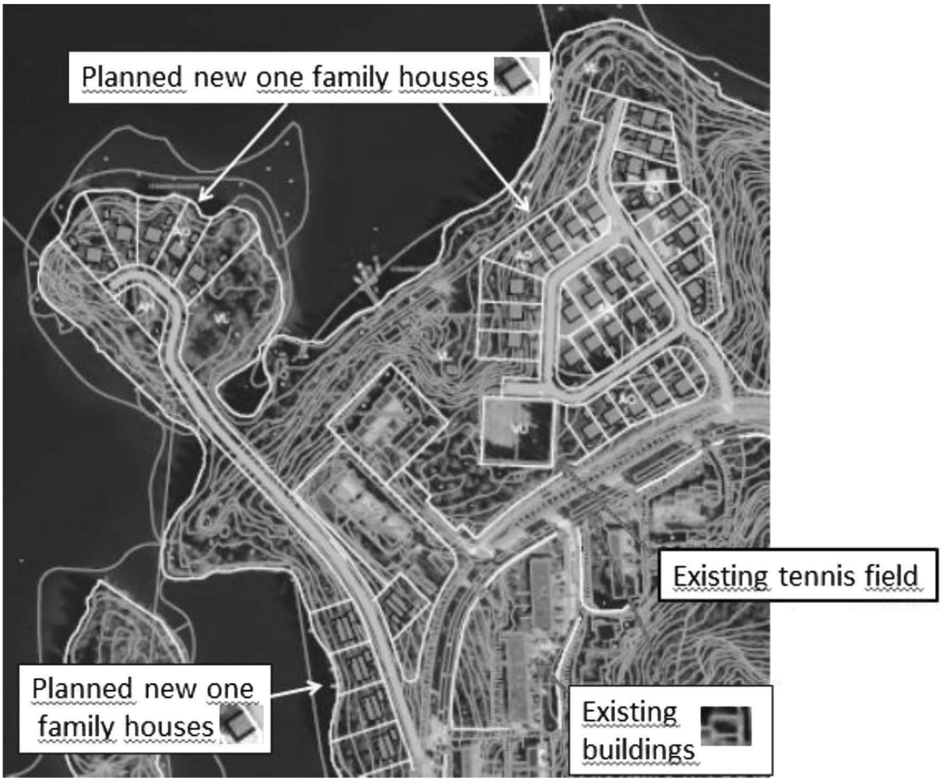


Fig. 7. Draft of the detailed plan of the Säynätsalo district (City of Jyväskylä, 2010).

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

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

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 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.

ARTICLE III

Energy saving potentials of Moscow apartment buildings in residential districts

Energy and Buildings (66), 706–713.

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

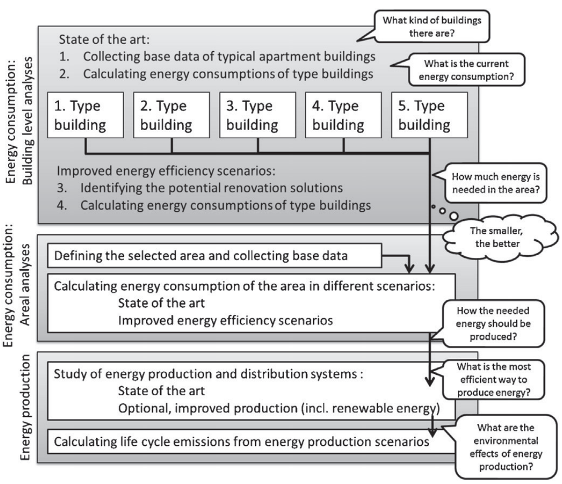


Fig. 1. The general methodology of the energy analyses.

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^{2}C° for wall constructions and 2.9 W/m^{2}C° 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.

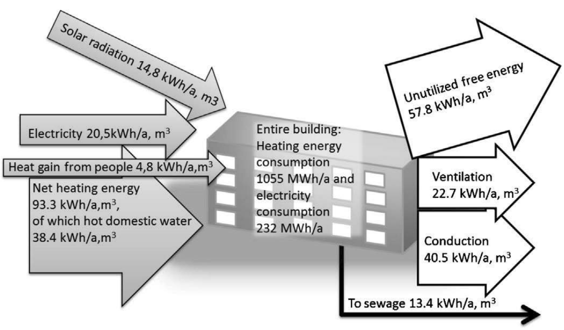


Fig. 2. The calculated energy streams of the apartment building II-18.

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

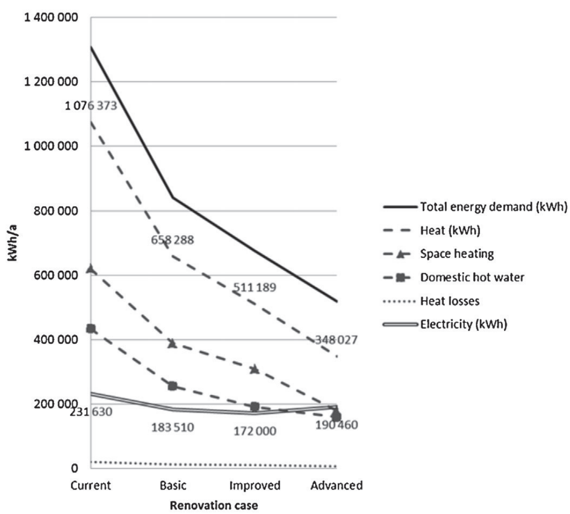


Fig. 3. Energy demand graph for the different renovation cases of the building II-18.

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 hence-society 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).

ARTICLE IV

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

Energy and Buildings (76), 402–413.

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

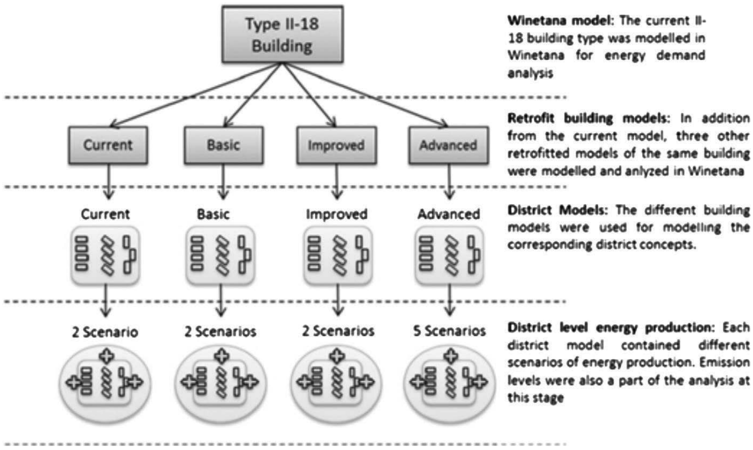


Fig. 1. Overview of the energy analysis process in this study (WinEtana is a computer software for making building energy analyses developed by VTT Technical Research Centre of Finland).

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:

$$\varepsilon'_{hi} = \frac{E_h}{n_h} \quad (1)$$

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

$$\varepsilon'_{ei} = \frac{E_e}{n_e} \quad (3)$$

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

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).

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

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.

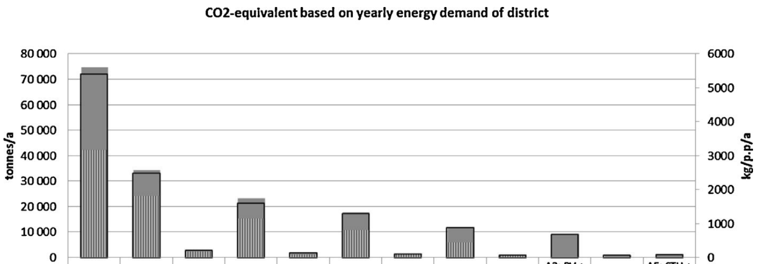
For the Advanced district concept the A3, A4 and A5 scenarios involving renewable energy were created in addition to the natural and biogas scenarios. In the A3 scenario, solar panels (PV) mounted on the roofs of the buildings was calculated to cover 7.5% of the total electricity demand, while the rest 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.

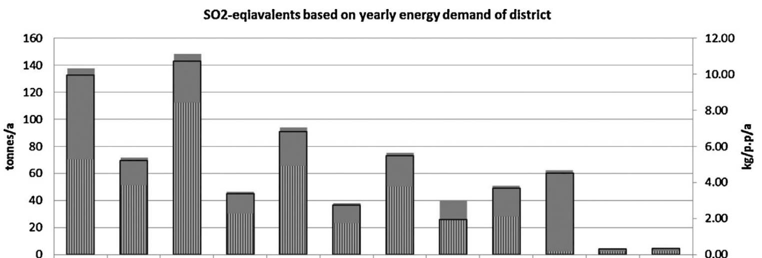
Based on the calculated energy demands (Table 4) the emissions for the Current district were calculated both for the existing natural

[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.

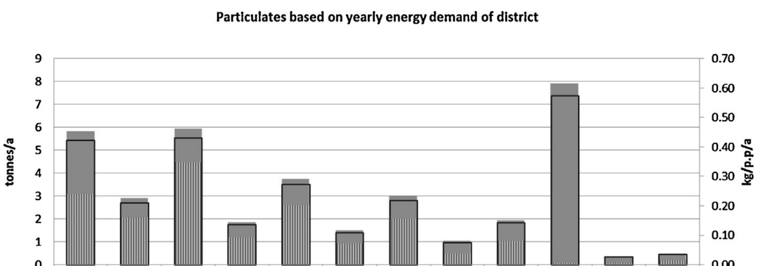
gas CHP plant and for an alternative biogas CHP plant. The emission from all the scenarios are pictured in Figs. 2–5.

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.

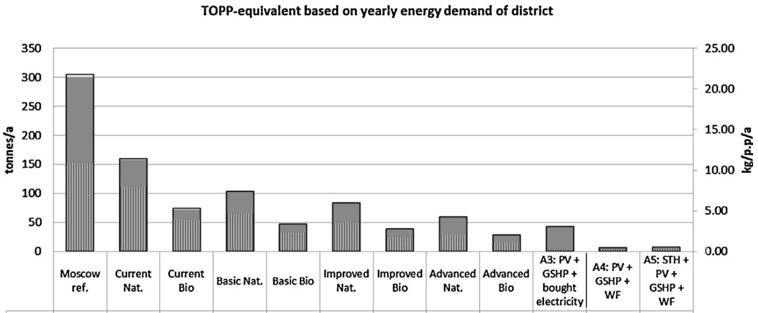
4.2.3. Emissions for the Advanced district scenarios

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-AppartmentBuildings-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, Öko-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).

ARTICLE V

Development of a concept for ecological city planning for St Petersburg, Russia

World Renewable Energy Congress 2011 – Sweden.
8–11 May 2011, Linköping, Sweden. 8 p.

Development of a concept for ecological city planning for StPetersburg, Russia

Åsa Nystedt[1,*], Mari Sepponen[1]

[1] *VTT Technical Research Centre of Finland, Espoo, Suomi*
* *Corresponding author. Tel: +358 40570 3798, Fax: + 358 20722 7015, E-mail asa.nystedt@vtt.fi*

Abstract: The aim of the research project, EcoGrad, was to develop a concept for ecological housing areas that would fit in St Petersburg. A criteria list for ecological residential areas was developed together with local partners. Some differing aspects between Finnish and Russian criteria are pointed out in this paper. These are among others the attitude towards high-tech solutions, the norms regarding placement of services, and the lack of well functioning service concepts for facilities. Three pilot cases were also studied. A rough plan was made for the pilot areas including placement of buildings and services and transport solutions. Energy systems were modeled and compared, and emissions were calculated. One of the pilot cases is shortly described in this paper. A questionnaire that was made to inhabitants showed a poor willingness to pay for renewable energy and good indoor air. Safety issues were highlighted, a majority does not feel safe in their living area.

Keywords: *City planning, Russia, Energy-efficiency*

1. Introduction

In Russia the ecological planning is still in the early stage of development. Energy production based on renewable energy sources is also a quite unknown solution. However, there are already some regulations that support the guidelines of ecological urban planning. One of these is the regulation that orders maximum allowed distance from residences to the daily used services, such as day care centre, school, shops and health care centre.

The aim of the research project, EcoGrad, was to develop a concept for ecological housing areas that would fit in St Petersburg. The project started in the beginning of 2010 and lasted until the end of the year 2010. The objective of this paper is to present the development process used in the project and highlight some specific differences in ecological city concepts developed for Russia compared to Finland.

As partner on the Russian side was the Coordination Center for International Scientific-Technology and Education Programmes. The most important reason for having a Russian partner was to develop the contacts to the local government. Another reason was to get help with collecting necessary basic data.

One of the guiding principles in the planning process of this project was the GOLD principle, which stands for “Globally Optimized, Locally Designed”. Practically this means that the local conditions are taken into consideration, when applying global optimized solutions into the EcoGrad concept.

The project included three pilot residential areas locating in St Petersburg. A rough city plan was drawn and different energy systems were modeled and calculated.

Based on findings from the pilot studies and negotiations with the local authorities, a criteria list for an ecological city plan was made, presented, and iterated.

2. Methodology

2.1. Progress and collecting data

The approach was in the beginning to collect basic data and directly create concepts for pilot areas. The general data needed was the energy efficiency level of houses being built today, ventilation systems normally used, energy prices and tariff systems, building norms, city planning process description, other relevant local regulations (such as distances to the daily services) etc. Case specific data needed was: existing transport solutions, maps of the areas, city planning situation, expected amount of inhabitants, etc. However, it turned out to be more difficult and time consuming to get reliable base data. Therefore the approach was changed. First a basic concept, based on Finnish base data, was developed. It was presented to the local authorities and adjustments were made based on the feedback received. The concept was made in more detail by adjusting it to three different pilot cases. The detailed concepts were again presented to locals and adjusted. The development process could be called an iteration process.

A student from Saint-Petersburg State University of Architecture and Civil Engineering made a one month visit to VTT in order to help with data collection. A rough examination of the Russian building norms was made.

2.2. Questionnaire study for residents in Russia

Together with Finec, the StPetersburg state university of Economics and Finance, a questionnaire for residents was made. The questions were made by VTT, and the questionnaire was performed by Finec. The questionnaire had 750 answers, 600 per email and 150 per telephone interview and face-to-face interviews. The survey was devoted to the living area conditions opinions, which included answers regarding the housing, buildings and living areas, transport etc.

The main finding was that almost all respondents (92 %) said that it is of no value for them to have their house heated with renewable energy. Less than half of the respondents (40 %) are willing to pay extra for good indoor quality, even though 80 % answered that they consider good indoor quality important. Security issues could also be highlighted, 72 % said that they do not feel safe in their neighborhood, which can be compared to a study made in Finland that showed that 81 % of Finnish people living in urban areas felt really or quite safe [1]. The respondents want big apartments, over 100 m2, and they want to want to see parks, green areas and water when they look from their window. What also can be noted was that a rather big part, 44 % of the respondents do not own a car, mainly due to economical reasons.

2.3. Modeling of pilots

For each pilot case, a plan of the area was done, including the structure of the area, building types and location of services as well as transportation solutions. Different energy systems were modeled and compared. At first step, the base data was collected and a plan of the area was done. Number of inhabitants, buildings and necessary service spaces were settled.

At the second step, energy consumption of the entire area was calculated in different scenarios: base case scenario, low energy building and/or passive house level. The consumption level of base case scenario was assumed to correspond to the energy consumption level of Finnish building regulations in 2008, because reliable sources about Russian consumption levels were not available. Consumption level of low energy and passive houses were also based on Finnish definitions [2; 3]. The energy consumption was calculated using the WinEtana program which has been developed by VTT.

Different options for energy production, based on renewable energy sources, were studied. Different suitable production technologies were recognized, and then emissions produced during the entire lifecycle of the energy production process were calculated and compared with each other. In addition, the distribution losses were also included in the calculations. According to IEA electricity transmission losses are 10,3 % and heat distribution losses 7 % [4]. The emissions from the energy production were calculated using the GEMIS tool (Global Emission Model for Integrated Systems), developed by The Öko-Institut e.V.

One pilot was a residential area for 20 000 inhabitants. It was developed together with Pöyry Oy. The plan included different building types: one family houses, row houses and high rise buildings. The second pilot was a residential area for 10 000 inhabitants, all residential houses were high rise buildings. It was developed with a local building company. One starting point for the plan was to develop an ecological city plan without creating any extra investment costs. Focus was therefore put on non-technical solutions. The third pilot was a smaller one, including only a few blocks. In that pilot focus was put on the development of public-private partnership business models.

3. Results

3.1. The EcoGrad concept

The target of the EcoGrad concept is an ecological urban planning process, which takes into account local Russian operational environment. A result of this process is to achieve an urban area, which is as eco efficient, functional and comfortable place to live, as possible.

One of the key issues of EcoGrad concept is an integrated planning process. This means that all urban planning fields are taken into consideration together already from the beginning of the planning process. In other words, the continuous co-operation of experts of different fields is really important. Then it is possible to find the solutions that are best for the entire system both environmentally and economically as well as functionally.

The fields that are included in the EcoGrad concept are: dense structure of the urban area, local environment and basis, energy efficient buildings, energy production mainly from renewable energy sources, sustainable transportation solutions, waste and water management and social issues.

In an energy system of the EcoGrad concept, the primary aim is to minimize the total energy consumption of the area. The main focus has to be concentrated on the energy usage of buildings as well as transportation, which are the most significant energy consumers. The energy consumption of buildings can be remarkably reduced with low energy and passive building technologies. On the other hand, the energy that is really needed in the area should be produced mainly from renewable energy sources. The optimization of the entire energy system, including heating, cooling, and electricity consumption and production, is important.

3.1.1. Factors affecting to the implementation of projects in Russia

The Russian building regulations can be found from the SNIP documents. SNIP is a set of regulations in the field of construction, enacted by executive state authorities, which contain obligatory requirements. SNiPs set general provisions, design requirements, rules of carrying out works and work acceptance, cost estimate guidelines. There are a large number of SNIPs, and each of them concentrates on one specific field. However, according to the Russian partners, the building regulations are currently under development process and the aim is to develop regulations toward European standards. In Russia, it is critical for all operations and projects to have sufficient amount of knowledge about Russian building codes and operation models.

Nowadays it is quite to arrange the maintenances services of residential buildings in StPetersburg. This is due to unclear ownership and management structures of facilities, as well as a poor level of the feature information of real estates and poor supply of services.. It is unclear who should pay for the service and that often leads to the situation that the service is neglected. This needs to be taken into account when presenting solutions that include technical aspects. This is one of the drivers (even though not the only one) that increase the interest for various Public Private Partnership business models.

Some solutions of EcoGrad concept are so multifaceted that it is necessary to have a private partner for maintaining and operating those. Without skilled private operator it cannot be assured that technical solutions operate efficient and ecologically enough, as planned. This is due to the fact that most of the solutions need special know-how and maintenance also after the construction phase. Depending on the used public private partnership model, private partner can also be responsible for financing, investing, designing, building, and owning of services or necessary facilities. When designing and choosing suitable business model, it is important to consider money flows, responsibility areas of each party and ownerships really carefully. It has to be clear, who pays to whom and for what duty.

3.2. The Criteria list for ecological urban planning in StPetersburg

The criteria list for an EcoGrad area was made based on the findings from the discussions with the local city planners and the development of pilots. It included aspects from the international LEED and BREEAM criteria and national Finnish criteria.

The criteria list is divided into following sectors: the structure of the area and land usage, landscape, buildings, energy, transportation, waste and water solutions. There are three categories in the criteria list: general level criterion, details and specifications of the criterion and special notices from StPetersburg. Here we will address differences between Finnish and Russian criteria.

Less focus can be put on the placement of services due to the fact that the norms already require that the services are placed close by. The need for bicycle routes is included despite the fact that bicycles are seldom used. To support the use of bicycles, security issues should be highlighted, both in terms of traffic security meaning separated lanes for bicycles and in terms of safe parking solutions to prevent the bicycles from being stolen.

The criteria setting includes that renewable energy sources should be examined. It has, however, become clear, that the development of renewable energy systems is not that common yet in Russia. One aspect was that the buffer zones for bio energy plants were not known by Russian partners. It was also a bit unclear whether energy wells could be drilled for the use of heat pumps according to the local legislation.

The passive house solutions need to be highlighted here. An important part of the passive house concept is the mechanical ventilation with efficient heat recovery. It needs to be emphasized that buildings can't be built airtight and well insulated unless the ventilation is in order.

Generally speaking it seems that passive solutions that aren't that technology dependent are valued higher in Russia. Technological solutions are not considered ecological, but contrary they are seen as potential additional electricity consumers, the mechanical ventilation being one example of this. Smart metering systems for electricity use was of interest but still considered with a bit of skepticism.

3.3. The concepts for the pilot cases

During the EcoGrad project three pilot areas were also studied. Comparing calculations of different energy system scenarios and emission models were made for each pilot model. In addition, in each pilot the focus was in some special aspect of the model. In the first pilot the focus was on the factors that affected to the eco efficiency of the area (such as public transportation as well as walking and bicycling, green corridors, different building type areas, cultivation plots, placement of services and the entire area etc). The special character of the second pilot was the requirement of not allowing any extra costs. In the third pilot, the public private partnership business models were investigated.

As an example the energy system, calculations of the first pilot are briefly introduced below. The plan of the first pilot area and the volumes are presented in the Figure 1. The planned number of inhabitants in the area is 20 000. The residential area is 30 m^2 per inhabitant, which means in total 600 000 m^2 floor area. There are five different building type areas: dense, low and dense, detached houses and villas. The inhabitation is most dense in the center of the area, which is really close to services and railway connection to the centre of StPetersburg.

Fig. 1.Plan of the first pilot

The energy consumption has been calculated in three different scenarios: base case, low energy and passive building levels. The results can be seen from the Figure 2. Most significant improvements are related to decreasing the heat consumption of buildings, and especially the heat consumption of space heating. It is more difficult to affect to the electricity or hot water consumption, because they depend more on the habits of the residents.

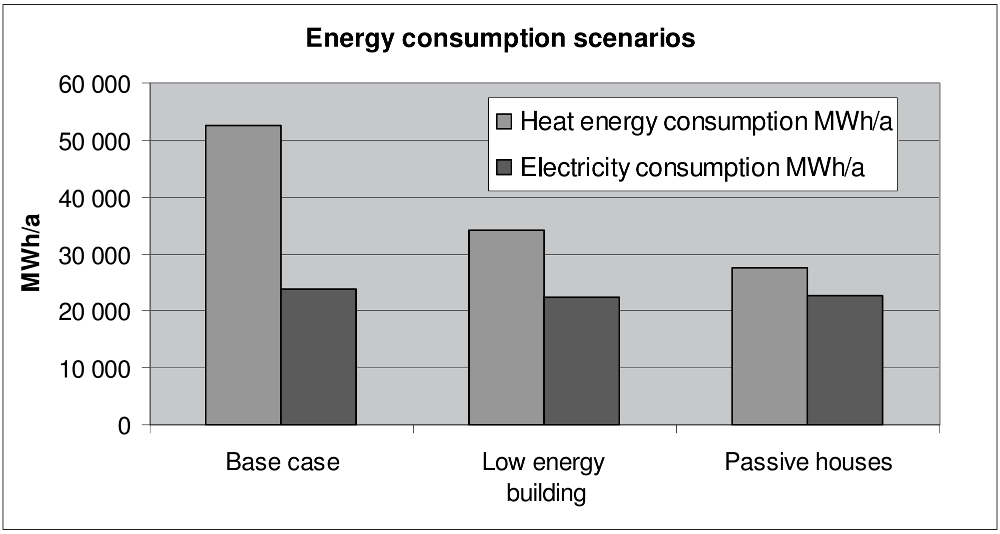


Fig. 2. Energy consumption of the pilot area in different scenarios

Next, different energy production options were studied. First option was quite ultimate with the target of using only renewable energy sources and achieving as low emission level as possible. That meant ground heat pumps, building integrated solar panels and wind power.

Heat collection pipes could be mounted on the golf court locating close to the pilot area. It was assumed that the COP of the heat pumps is 3, and the heat yield is 35 kWh/m2/a. One of the challenges was the fact that heat pumps consume electricity, which is also supposed to be produced within the area. If was further assumed that the entire area of roofs could be utilized with building integrated solar panels. It was calculated that the yield of solar panels would be 17 700 MWh/a. This means that there should also be a lot of wind energy: in a base case 28 804 MWh/a (the power capacity being 14,4 MW), low energy building level 20 200 MWh/a (with the power capacity of 10,1 MW) and passive building level 17 796 MWh/a (with the power capacity 8,9 MW). Power levels of wind power are calculated with a capacity factor 23%. In this option the target was to produce as much energy as is consumed in the area, but it is assumed that the area is connected to the national electricity grid, which smoothes the differences between the production and consumption continuously.

The second option was combined heat and power production (CHP) plant that is fuelled with woodchips. The third option was also a CHP plant, but it was fuelled with biogas produced from the wastes. It was assumed that the CHP plant is operated according to the heat demand in the area, as usual. In addition, it was assumed that the plant produces 80 % of yearly heat consumption, and the rest of the heat demand is covered with reserve plants, for example natural gas boiler. The used CHP processes were calculated with the information of real existing plants from the database of the GEMIS software. The plant using wood as a fuel produced 2 MWh of heat per 1 MWh of electricity, with the electrical efficiency of 27,5 % and operating time of 6000 h/a. The biogas CHP plant produced 1,5 MWh of heat per 1 MWh of electricity, and the efficiency and operating time were the same as the woodchip CHP plant.

The green house gas emissions of these different energy production options are presented in Fig. 3. The emission calculations include the emissions produced during the entire life cycle of their processes (including for example construction and transportation). These results were also compared to the base case, which represents the current situation in Russia. According to IEA, in Russia buildings are heated most commonly with district heating, in which the heat is produced from natural gas. The emissions of base case electricity are calculated with GEMIS from the base data of IEA [4].

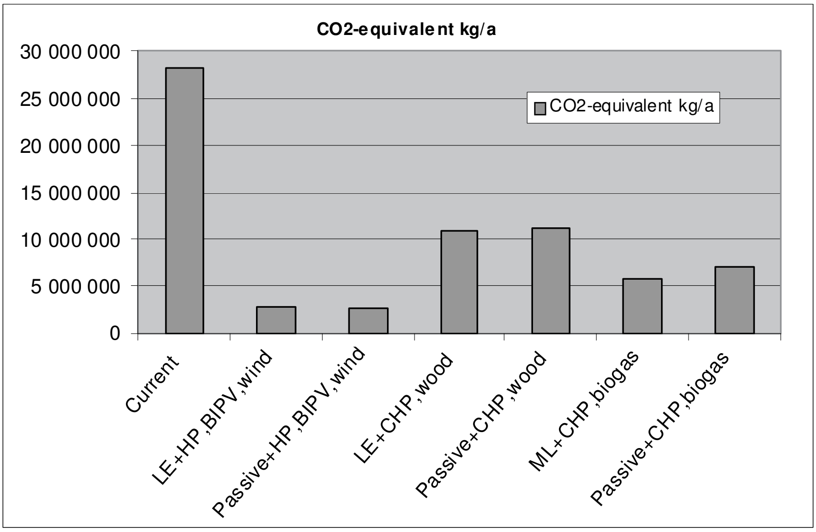


Fig. 3. Green house gas emission from different energy production options in the first pilot case. (LE = low energy buildings, Passive = Passive buildings, HP = heat pump, BIPV = building integrated solar panels, CHP, wood = CHP plant that uses woodchips, CHP, biogas =CHP plant that uses biogas)

In the second pilot study, the same options were studied as in the first pilot. But moreover, it was also studied what could be done, if no extra investment costs are allowed. That means that electricity is bought from the national grid. The most promising for heat production in the area was district heating with woodchip boiler.

The third pilot, which was the smallest and had only less than 2000 resident, is located by the coast, on the Vasili island, in central St Petersburg. Therefore, the water heat pump solution was considered interesting. And besides heating, heat pump could also be utilised for space cooling. The electricity could be produced with building integrated solar panels as well as with small building integrated wind turbines. This solution produces all the heat and cooling energy consumption of the area, but still 71 % (in passive building level) and 79 % (in base case) of the electricity consumed in the area should be bought from the national grid. In addition, a heat supply system with solar collectors was modelled.

4. Conclusions

One conclusion of the project was that it is of great importance to have an active local partner in this type of development project. The local partners need to have their own funding for the project to ensure that the work is being prioritized.

Taking the criteria developed in this project into the planning process is the next step in the development of new ecological areas. There seems to be a difference in the mindset of the Russian people compared to Finnish people. More effort should be put on understanding the needs of the inhabitants. The end-user should be included more in the planning process.

There seems to be a lack of knowledge regarding renewable energy systems and technologies for building energy efficient houses. Efforts should be put on exporting knowledge and best practices about these issues. With an increase of knowledge the local norms can be developed in a sustainable way and it will also support the development of the city planning process.

References

[1] P. Suominen, Suomi - Euroopan turvallisin maa?. Reseach report. Poliisin ylijohdon julkaisusarja 7/2009, ISBN 978-952-491-434-5. Referred 12.12.2010. http://www.poliisi.fi/intermin/biblio.nsf/3D6379853B32E72DC225768C003279F0/$file/7-2009.pdf

[2] I. Strom, L. Joosten, Boonstra, J. Nieminen, M. Saari, E. Nykänen, Työraportti 1.2 Passiivisen talon ratkaisut. Work report of Promotion of European Passive Houses project. 2006. Referred 10.12.2010. Available: http://erg.ucd.ie/pep/pdf/Passive_House_Sol_Finnish.pdf

[3] J. Nieminen and K. Lylykangas, Passiivitalon määritelmä. Ohjeita passiivitalon arkkitehtisuunnitteluun. 2009. Referred 10.12.2010. Available: http://www.passiivi.info/download/passiivitalon_maaritelma.pdf

[4] IEA, Electricity/Heat in Russia Federation in 2008. Referred 2.9.2010. Available: http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=RU

Appendix B. Description of research projects

HETRA – Technical features for heat trade in distributed energy generation

The aim of the project was to develop a concept for heat trading and analyse its potential and impact.

Liberated heat market works mainly like a liberated electric market in Nordic countries with the exception that heat market works within a local district heating network. There are producers, customers, a network operator and a system operator as there exist in the electric market. Physical actors are the traditional large scale producers that sell heat to customers connected to the district heating network, and the end users, that would also be small-scale producers using a micro-CHP or a boiler. They would buy heat from other producers or sell heat to customers through the network. The liberated heat energy market will also need the transmission network company that takes care of the temperatures, pressures and hydraulic balance of the heating network. A balance-sheet operator is also needed to coordinate the heat contracts between producers and customers as well as to take care of reserve capacity, spot and future markets and billing.

The requirements for the district heating network design in the heat trading context are an aspect that still requires further attention. Our simulations showed that temperature changes were occasionally quite rapid in some parts of the network. They were caused by stagnation of flow in some loops of the network, where flows come from different directions. Small producers seem to bring more time-varying factors into the system. This might lead to a new district heating network design approach where temperature variations can be minimized. The four different physical connection types for the small scale producer in the building side were studied and the recommended connection version was found. The recommended connection version is type 3, in which the small scale producer is connected to the DH-network via heat exchanger. This connection has advantages compared to the other versions: it does not bring any changes to the standard modular substation unit in buildings, it is a safe solution to the user (no water leaks) and to the DH network (no gas leak problems), it is easy to control, it is suitable for new installations and renovations, and maintenance of the CHP unit does not cause any problems to the DH operation. In general, we found out that the physical connection will need standardized rules, in which the quality and the performance of the connection unit are unambiguously defined, same way as the current Finnish Energy Industries/District Heating Departments' (earlier Finnish District Heating Association) guidelines do for the district heating substations. However, these new building level guidelines of the small scale producer were not defined in this study. Real option analysis is adopted to evaluate the risks of investment when electricity price and heat price are uncertain.

Results from the project are published in the online publication:

http://www.vtt.fi/inf/pdf/tiedotteet/2005/T2305.pdf

Ekotaajama

The main objective of the Ekotaajama project was to develop a district level energy rating classification system and to develop a tool for city planners for assessing the energy efficiency of detailed city plans. In addition several district level energy analyses were done in the 5 case districts comparing different energy solutions for the districts and analysing their impacts on emissions. The project was funded by Sitra, Tekes and the Finnish cities Jyväskylä, Toivakka, Multia, Petäjävesi, Jämsä and Kannonkoski.

A district's energy efficiency is mainly influenced by the buildings energy consumption, energy production methods and traffic. Inhabitant's behaviour also influences the energy consumption significantly. This project focused on design solutions that can be influenced through the detailed city plan. A significant limitation of the work was focusing only on solutions made within the district. This leaves out most of the impacts of traffic since most of the traffic is to and from the districts because of their nature being smaller rural districts. It needs to be emphasized that the placement has a significant impact on the overall energy efficiency of the districts. The traffic can be minimised by the detailed city plan by providing daily services close to the residents. This can, however, be challenging in the rural areas with no dense city structure.

The energy classification system is a way to influence the buildings energy demand in the city plans. Tighter energy classifications than what the law requires can be set in the plans. The building inspectors have an important role in advising house builders in building energy efficient and high quality houses. Many things influence the choosing of the energy system. In the city plan it can be decided to connect to the district heating system. Other energy systems can be only recommended, not enforced. The building instructors can actively recommend the possibilities of renewable energy systems.

A tool for assessing the energy efficiency of a district was developed within the Ekotaajama project. The tool helps with comparing the impacts on energy efficiency by different choices made in the city plans. The purpose of the tool is to compare solutions made within districts, not to compare districts with each other. The Ekotaajama district are rural and typically consist of one family houses. People on the countryside want to live in one family houses not too close to each other. The sparsely structure adds to the need of using private cars for moving around. These are aspects that need to be accepted. This rules out some of the principles of EcoCity planning, but still there are many things that can be done in order to create nice and energy-efficient living conditions.

The projects final report (in Finnish): http://www.vtt.fi/inf/pdf/technology/2012/T24.pdf

ModernMoscow

The project was carried out during 2011–2014 and was funded by the Ministry for Foreign Affairs of Finland. The aim of the project was to prepare a wide feasibility study for the energy-efficient and sustainable renovation and modernization of a selected district in Moscow, Russia.

The emphasis is on technical solutions and their energy-saving potentials and possible reduction in emissions. District heating is mainly used for space heating in Russian apartment buildings. Due to the technical structure of the district heating used in Russia, energy renovations of single buildings seldom lead to reduced energy production. Energy production demands are reduced only if the residential districts and their various utilities and networks are renovated holistically.

During building renovation, existing and future criteria for sustainability should be taken into account. Sustainability criteria for energy-efficient renovations of Moscow apartment buildings and districts were developed based on criteria developed for new residential districts in Saint Petersburg. The criteria setting includes criteria for planning structure/functional planning, the surrounding terrain, buildings, transport solutions, waste disposal and energy supply. A typical Moscow residential district was selected for analysis. First, a state-of-the-art was produced of energy performance, and water and waste management of the buildings and of the district. Then alternative energy renovation concepts reducing the environmental impacts of the buildings and the district were developed and analysed.

The building renovation concepts, named Basic, Improved and Advanced, were adjusted in such a way that each of them becomes an improvement on a previous one as regards the total annual energy demand. The basic concept refers to minimum, low-cost or easy-to-do renovation measures. The improved renovation concept outputs better energy or eco-efficiency. The advanced renovation concept suggested the most progressive solutions. Based on the calculations, the building level energy saving potential was up to 68% for heating energy and 26% for electricity.

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

The different renovation concepts were also analysed from an economic point of view. All the building level packages covered improvements of external walls, windows and doors, upper ceiling, basement, ventilation, heating system, water and wastewater, electricity, gas, metering, and other improvements and costs but the selected products and solutions varied from basic through improved to advanced ones.

The district renovation concepts were aligned with the building renovation packages, and the costs of building renovations were included in the costs of improving district energy and water infrastructure in the pilot Moscow district.

Financing renovations is often a major barrier in any country. This topic was also addressed in the project. Most of the housing units in apartment buildings are privately owned due to the free privatization after the Soviet collapse. However, no sustainable form of self-financing apartment renovations has existed, and former lessors of residential units still have the obligation to carry out capital repairs.

Existing and new financing mechanisms, including public-private-partnership (PPP), are introduced in the results. Regional and local budgets are still the main financing mechanisms for capital repairs in Russia.

The project also examined possible business models for energy-efficient renovations of residential districts in Russia. An important part of this is the stakeholder analysis carried out by the relevant actors involved in district renovations in Russia.

Projects results have been published in the following online publications:

http://www.vtt.fi/inf/pdf/technology/2013/T82.pdf

http://www.vtt.fi/inf/pdf/technology/2014/T154.pdf

EcoGrad – Ecological City Planning Concept for St Petersburg, Russia

The EcoGrad project was carried out 2010. The project was financed by the Ministry of Foreign Affairs of Finland. The objective of the EcoGrad project was to develop a design concept of eco-efficient districts in the city of St. Petersburg. Emphasis was put on taking local conditions into account while applying globally optimized solutions. The EcoGrad concept includes dense city development, a minimal need for travel, a maximum use of public transportation and light vehicles, minimum power consumption, the maximum use of renewable energy sources and ecologically stable solutions concerning waste disposal and sewerage. Social and cultural aspects must also be taken into account.

In Russia, the creation of energy efficient sites is still in its early stages. Power supply systems based on renewable energy sources are also hardly known. On the other hand, the Russians are well skilled in placing offices and consumer services next to residencies. Regulations dictate the maximum allowable distances between residential buildings and such services as infant-care groups, kindergartens, schools, ambulatory clinics and stores, fully conforming to the principles of designing ecoefficient city districts.

While the project was being implemented, residents were polled. The polls revealed that the absolute majority of them (92%) did not consider the use of renewable energy sources important. Most of them (80%) had not heard of mechanical ventilation. Fresh air is considered important yet less than half of all respondents (40%) are prepared to pay for it. Involving residents in the development process, that is, the so-called LivingLab action is an important component of designing eco-efficient residential areas. In Russia, the participation of residents should be further extended and made a part of the design work.

The project concerned three pilot territories for which residential designs were made. The designs included estimates of power consumption and a study of the distribution of emissions when using various energy supply systems suitable for local conditions. Besides, a design providing for better ecology without any greater investment was made for one of the pilot sites. The PPP (Public-Private-Partnership) pilot project involved the development of practical models of project implementation.

While this work continued, seven meetings with representatives of St. Petersburg administration were held. During these meetings, a presentation of the components of this concept was made and opinions heard as to how its various sections would suit local conditions. These opinions were put in the basis of the list of the criteria of designing environmentally clean areas presented in the projects final report. Local designers may use this list while searching for answers as to requirements to city designs which need to be met in order to make residential areas eco-effective.

Projects results have been published in the following online publication (available also in Russian and Finnish): http://www.vtt.fi/inf/pdf/tiedotteet/2010/T2566.pdf

Appendix C. Questionnaire for Finnish city planners and Housing and living area survey in St Petersburg

1. Questionnaire for Finnish city planners

The objective was to perform a questionnaire that had a relevant set of questions which would make it easy for the respondents to understand and answer. The expert groups chosen to participate in the survey were urban planners and building inspectors. The urban planners make plans while the building inspectors see through that the plans are being followed.

The questionnaire form was created on an internet based application Digium Enterprise which was provided by the Questback Company. A link to the questionnaire form was thereafter sent to around one hundred urban planners and three hundred and fifty building inspectors in different municipalities of Finland. Each building inspector represented one of the municipalities of Finland. The urban planners were those who are involved in detailed planning from municipalities that have a department for urban planning of their own. The questionnaire was performed in 2012.

Below the questions and the replies are shown. Open replies have been left out in this summary.

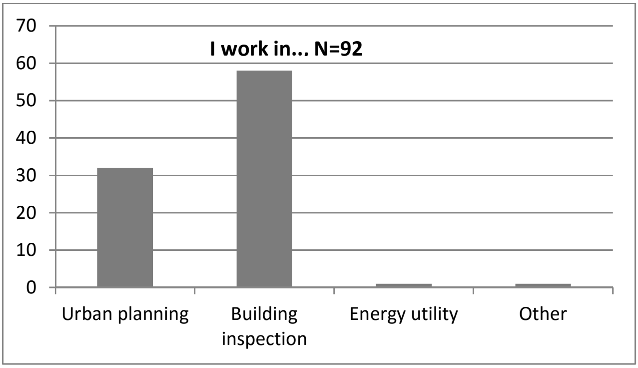


Figure 1. Role of respondent

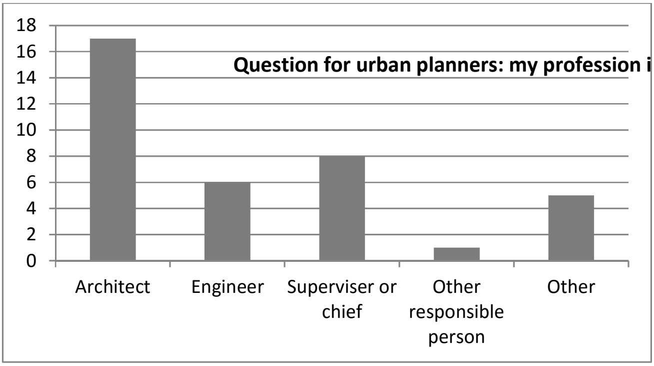


Figure 2. Specifying question for urban planners.

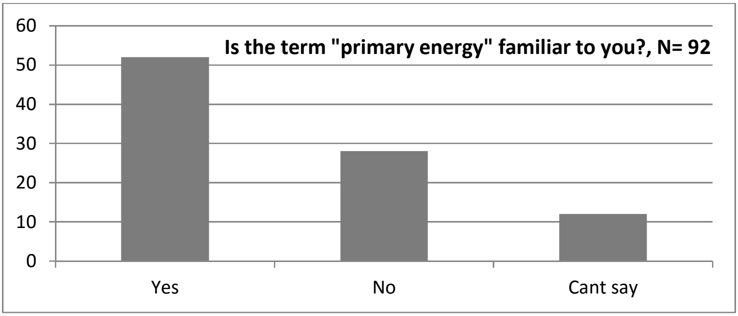


Figure 3. Question: Is the term "primary energy" familiar to you?, N= 92

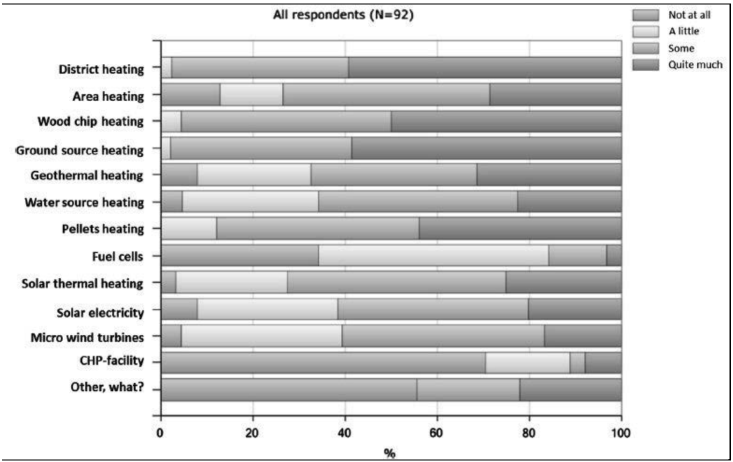


Figure 4. Result of the question "How familiar are the following energy systems"?

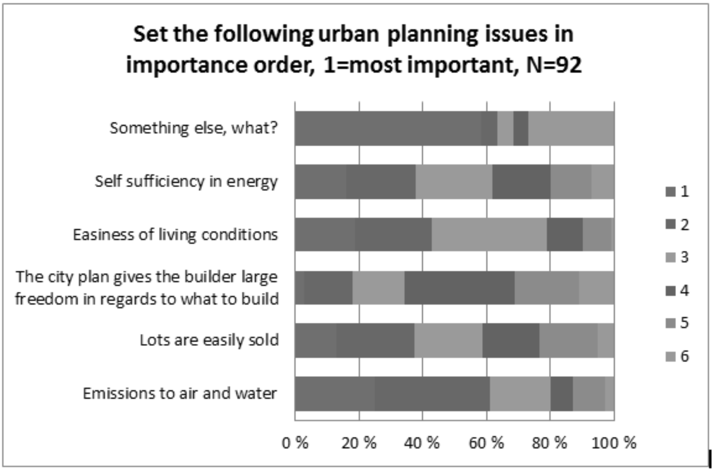


Figure 5. Set the following urban planning issues in importance order, 1=most important, N=92

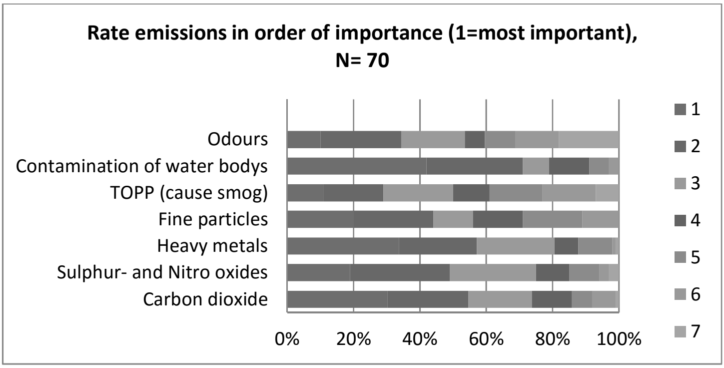


Figure 6. Rate emissions in order of importance (1=most important), N= 70

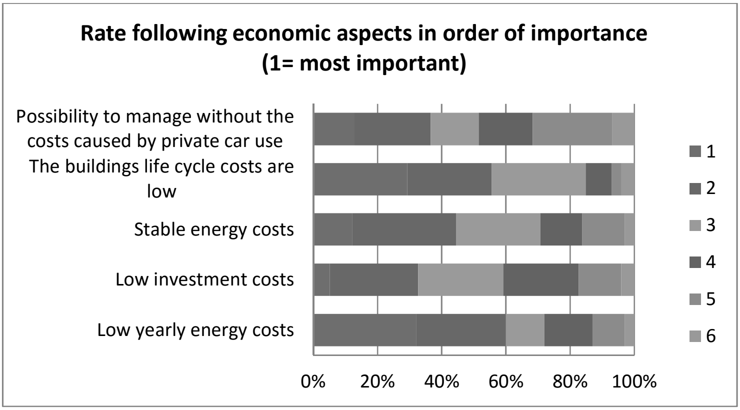


Figure 7. Rate following economic aspects in order of importance (1= most important)

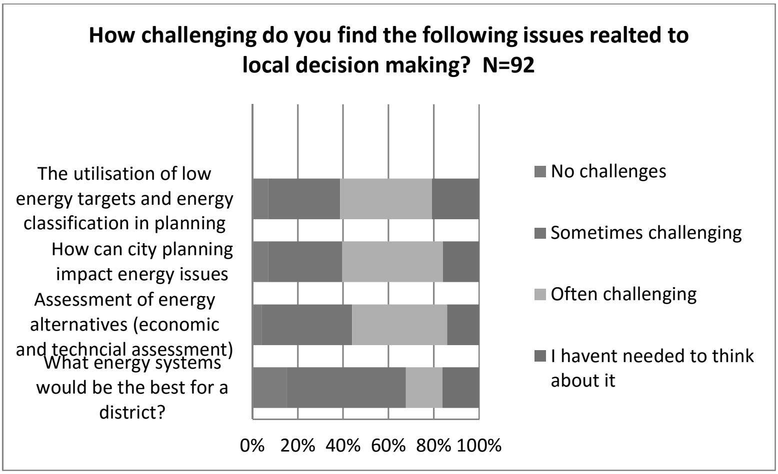


Figure 8. How challenging do you find the following issues related to local decision making? N=92

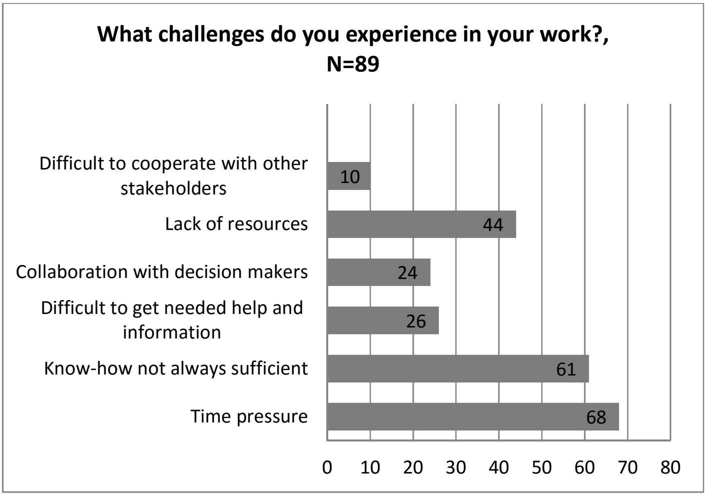


Figure 9. What challenges do you experience in your work? N=89

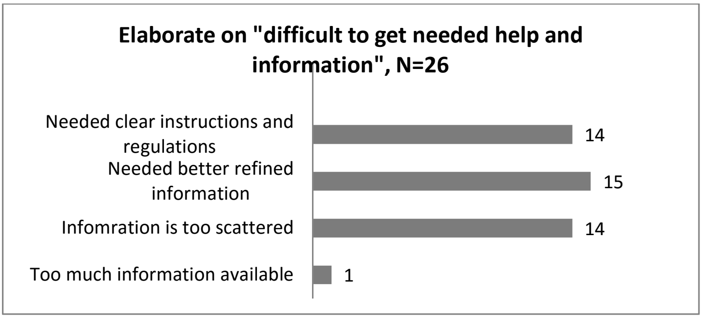


Figure 10. Elaborate on "difficult to get needed help and information" N=26

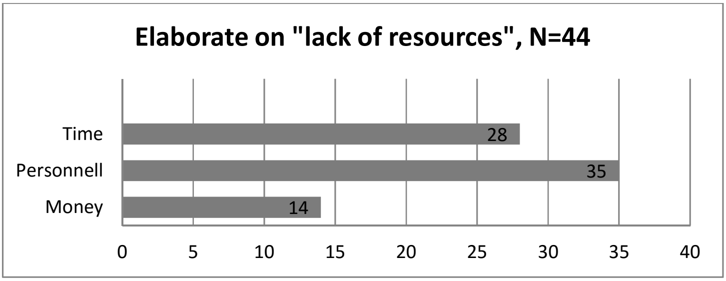


Figure 11. Elaborate on "lack of resources" N=44

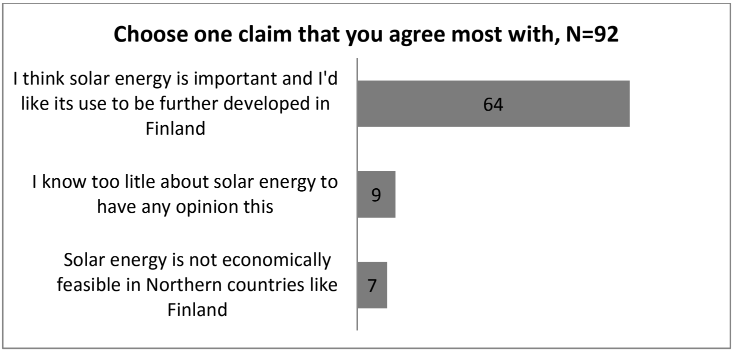


Figure 12. Choose one claim that you agree most with. N=92

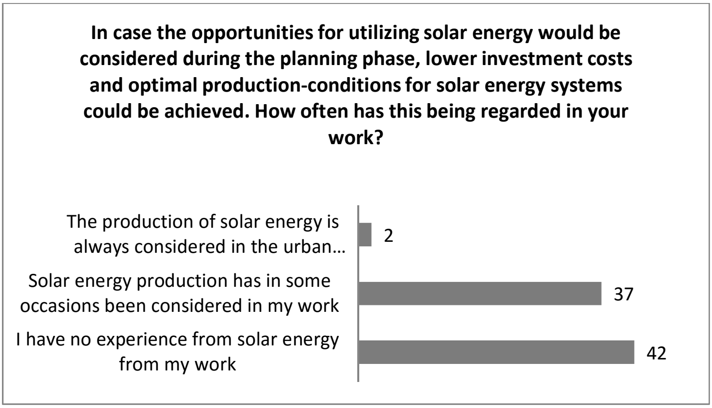


Figure 13. Solar energy being considered in the work.

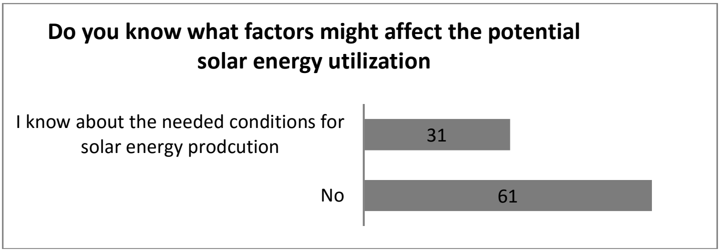


Figure 14. Knowledge about factors affecting solar energy potential. N=92

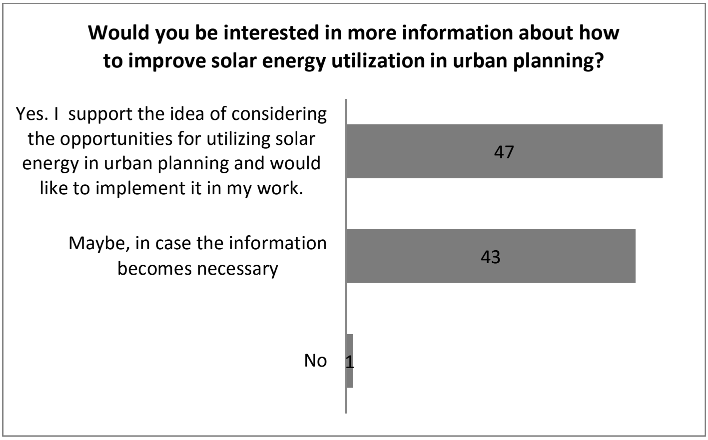


Figure 15. Interest of more information.

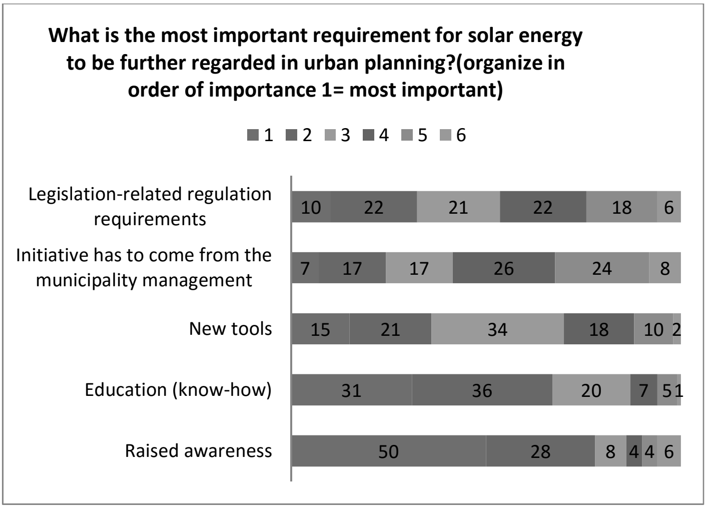


Figure 16. Requirements for solar energy becoming more regarded in urban planning.

2. Housing and living area survey in St Petersburg

Authors: Åsa Nystedt and Mari Sepponen, VTT, Maria Apresyan, Finec

As part of the EcoGrad project, which was financed by the Ministry for Foreign Affairs of Finland, a housing and living area survey was conducted. It was done together with Finec, St Petersburg state university of economics and finance. The content of the survey was done by VTT and the survey was conducted by Finec.

The survey was conducted by 30 Finec Master students in the period of 20/10/2010–15/11/2010. The task was to poll at least 20 persons via e-mail/phone and at least 5 persons via in-depth interview. The students were very concrete and we got exactly 750 answers – 600 e-polls and 150 in-depth interviews.

The survey was devoted to the living area conditions opinions, which included answers regarding the housing, buildings and living areas, transport etc.

The results were used in the development work of the ecological city criteria. For future development work the survey could be deeper and also take into account other parts of Russia than St Petersburg. Analysing differences in different regions could be highly interesting.

2.1 The survey

Basic information:
Gender
Age
Size of family
Education level
Income level
Living conditions now:

apartment/one family house/row house/other?

Own apartment/house, rental…other?

Questions:

- About the house/apartment
  - How big apartment is desired, m^2 and number of rooms
  - Is thermal comfort considered important? (draft? too cold/too hot?).
    - Have you in your home had problems with this?
    - Are you willing to pay money for increase thermal comfort? How much?
    - Is it important to be able to adjust the temperature
  - Is fresh air inside important?
    - Willing to pay money for better indoor air quality?
  - Have you heard about mechanical ventilation systems?
    - Any opinions about such systems?
  - Is a balcony important?
    - Willing to pay more if an apartment has a balcony? How much?
  - Is a garden lot important?
    - Willing to pay more if an apartment/a house has a garden lot? How much?
  - Do you consider it important to measure your electricity and heat use?
    - Why? Why not?
  - Interest of having real time monitoring of electricity and heat?
    - Willing to pay for this? How much?
  - Do you consider water saving important?
  - Do you consider electricity or heat energy saving important?
    - Why? (economical/environmental reasons/other reasons?)?
  - Metering of water use important? Do you see any advantage of this?

    - Would it be a value for you if your house was heated with renewable, “green” energy?
        - Willing top pay for this? How much more than normal heating fee (in %)?
    - Would it be a value for you if your electricity was produced with renewable, “green” energy?
        - Willing to pay for this? How much more than normal electricity fee (in %)?
    - What is the most important factors for you when buying a house/apartment?
    - What is the most important factors for you when renting a house/apartment?
    - When you are buying electrical equipment, do you pay attention to its energy efficiency? Are your ready to pay more to get energy efficient equipment? How much more?
    - If you live in an one-family-house, are you ready to use your time and effort to take care of the heating system of your house? How much? Do something everyday? Once a week? Once a month?

- About the residential district
    - What is important to have close to your house? (green areas? playground? shops? other services? public transportation? water (like a river or sea…)? etc… in importance order.
    - What do you want to see when you look out from your window?
    - Do you own a car?
    - Do you have public transportation close to you?
        - Do you think the public transportation is cheap/expensive?
        - How much do you think a daily/monthly fee for public transportation within the city should cost?

    - If yes:
        - Do you use your car instead of public transport in daily life? If yes, why?

    - How close to your home do you feel that you need to have a parking place?
    - How close to your house do you feel that you want to have a station for the public transportation?
    - How much longer time can your daily trip (to work/school) take with public transportation than with car, for you to still consider the public transportation?

- If no car:
    - Why don’t you have a car? (economical reasons? ecological reasons? no need for a car? other?)

- Do you feel safe in your living area?

- Is safety issues important when considering a new living area?
    - How does this come into practice? What makes an area safe?

- Do you use bicycle, or do you walk your daily rout? How long distances are you ready to cycle or walk? How often (every day/weekly/monthly/in the summer…)

- Do you recycle your waste?
    - If yes, what materials (paper, plastic, metal)?
    - If no, why not (not possible, too difficult, recycle bins too far away, not interested, don´t know why it should be done…?)

2.2 Results

Basic information

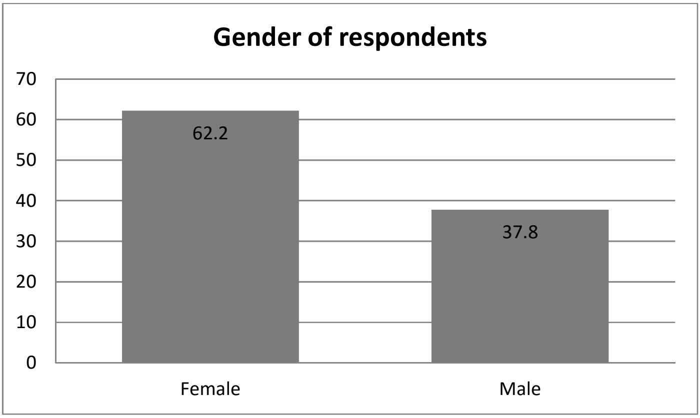


Figure 17. Gender of respondents

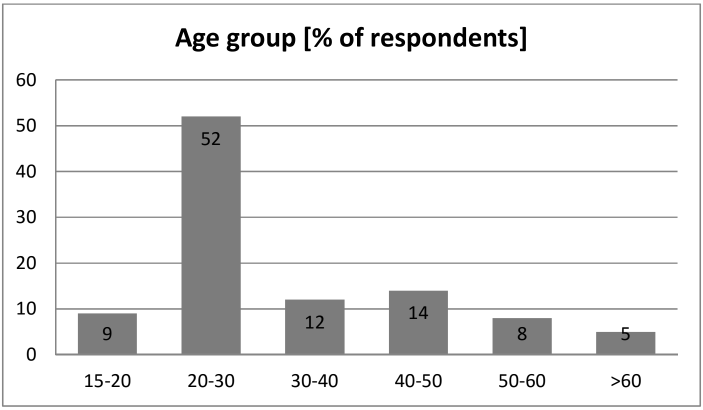


Figure 18. Age group of respondents

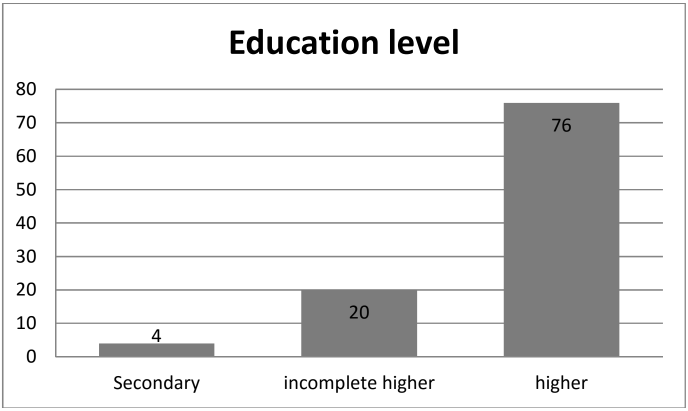


Figure 19. Education level of respondents

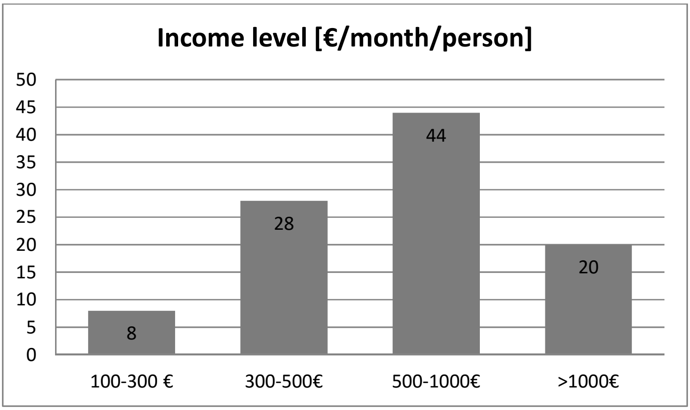


Figure 20. Income level of respondents

About the house/apartment

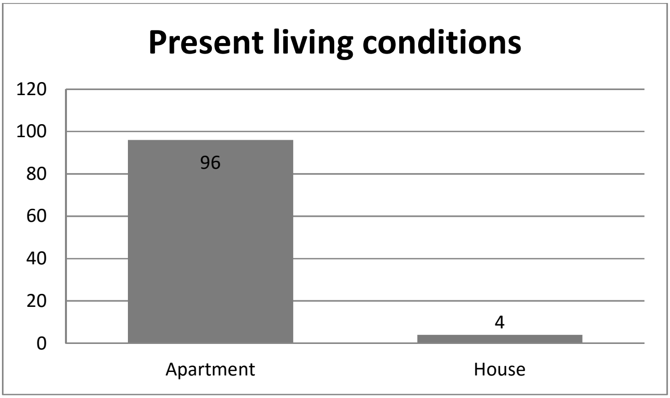


Figure 21. Present living conditions of respondents

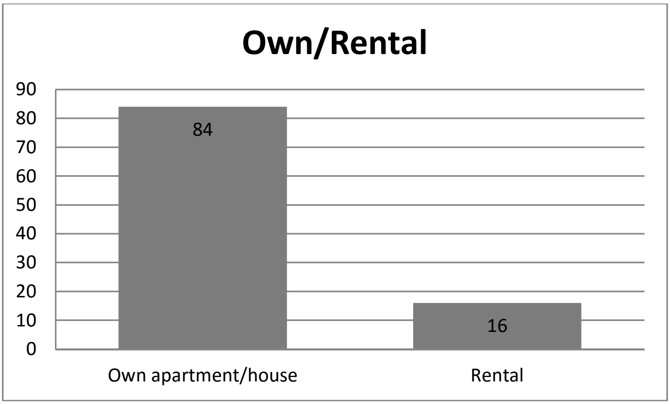


Figure 22. Own or rental apartments

- Most of the people desire apartments > 100 m², 3–5 rooms.

- It turned out that 92% of people have no problems with thermal comfort in their houses and suppose that the temperature. For the respondents thermal comfort considered important, but just a few of them are willing to pay for it.

- For most of the people (80%) also is important to be able to adjust the temperature and to have a fresh air inside.

- Just 40% are willing to pay money for better indoor air quality.

- About 80% of respondents have never heard about mechanical ventilation systems.

- For most of the respondents Balcony has a meaning (for balcony main reasons smoking place or storage facilities), but not all of them are ready to pay for it.

- For 36% of people a garden lot is important.

- All of the respondents said that it was important to measure their electricity and heat use, because it helps save natural resources and it helps economise on bills.

- Most of the respondents (92%) said that it wouldn't be a value for them if their house was heated with renewable, "green" energy.

About the residential district

- The most important factors for people when buying or renting a house/apartment is location, then follows planning and price. People prefer to have green areas, shops, public transportation and also water next to their houses. About 72% of people want to see parks, green areas and water when they look from their window. For others the view in not so important.

- 56% of respondents own a car, because they appreciate comfort. Other 44% don't have a car because of economic reasons, because they don't need and 4% are afraid to drive a car. People who have a car usually use their car instead of public transport in daily life, because it's more convenient.

- 76% have a public transportation next to their houses. Most of the people consider public transport expensive. The answers about cost are very different (500 RUB, 80 EUR, 30 EUR, 1000 RUB, 550 RUB, 60-70EUR, etc.).

- Most of the people (72%) don't feel safe in their living area. But for everybody safety issues are important when considering a new living area. Buying an apartment in a safe place with security systems, video cameras, expensive restaurants or hotels nearby can make an area safe.

- Just few respondents use bicycle, because their homes are too far from universities/work. People usually use their cars or public transport.

- Nobody recycles their waste due to the lack of facilities

Aalto-DD 10/2016
VTT SCIENCE 123

This thesis focuses on energy-efficient urban planning and the role of legislation within that context. The objective of the thesis is to analyse if energy-efficiency of districts is improved by a regulative approach into planning, if proper tools and guidelines to support the planning are available.
The thesis gives concrete recommendations for how to improve the regulations in the city planning process to enable a more energy efficient built environment.
The recommendations' overall aim is to increase the quality of life and to increase the welfare of the society as a whole.
Allowing stakeholders to plan solutions based only on their own interests, leads to sub optimised solutions. Energy-efficiency is a multidimensional issue which seldom can be achieved by sub optimisation. Our society is facing such tough times in terms of energy usage and emissions that a stricter more regulative approach to planning is needed.

ISBN 978-952-60-6621-9 (printed)
ISBN 978-952-60-6622-6 (pdf)
ISSN-L 1799-4934
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)

978-951-38-8391-1 (printed)
978-951-38-8390-4 (pdf)
2242-119X
2242-119X (printed)
2242-1203 (pdf)

Aalto University
School of Engineering
Energy technology
www.aalto.fi

BUSINESS +
ECONOMY

ART +
DESIGN +
ARCHITECTURE

SCIENCE +
TECHNOLOGY

CROSSOVER

DOCTORAL
DISSERTATIONS