VTT RESEARCH NOTES 2581

Juha Forsström, Pekka Lahti, Esa Pursiheimo, Miika Rämä,
Jari Shemeikka, Kari Sipilä, Pekka Tuominen & Irmeli Wahlgren

Measuring energy efficiency

Indicators and potentials in buildings, communities and energy systems

VTT TIEDOTTEITA – RESEARCH NOTES 2581

Measuring energy efficiency

Indicators and potentials in buildings, communities and energy systems

Juha Forsström, Pekka Lahti, Esa Pursiheimo, Miika Rämä,
Jari Shemeikka, Kari Sipilä, Pekka Tuominen & Irmeli Wahlgren

ISBN 978-951-38-7707-1 (soft back ed.)
ISSN 1235-0605 (soft back ed.)

ISBN 978-951-38-7708-8 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 1455-0865 (URL: http://www.vtt.fi/publications/index.jsp)

JULKAISIJA – UTGIVARE – PUBLISHER

VTT, Vuorimiehentie 5, PL 1000, 02044 VTT
puh. vaihde 020 722 111, faksi 020 722 4374

VTT, Bergsmansvägen 5, PB 1000, 02044 VTT
tel. växel 020 722 111, fax 020 722 4374

VTT Technical Research Centre of Finland, Vuorimiehentie 5, P.O. Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 4374

Cover page photograph: Esa Pursiheimo

Kopijyvä Oy, Kuopio 2011

Juha Forsström, Pekka Lahti, Esa Pursiheimo, Miika Rämä, Jari Shemeikka, Kari Sipilä, Pekka Tuominen & Irmeli Wahlgren. Measuring energy efficiency Indicators and potentials in buildings, communities and energy systems. Espoo 2011. VTT Tiedotteita – Research Notes 2581. 107 p. + app. 5 p.

Keywords energy efficiency, production, building, community, chain, potential, indicator, meter

Abstract

The European Commission implemented a strategy for Climate Action in 2008. According to that strategy, the Member States will reduce their collective greenhouse gas emissions by at least 20% and boost the share of renewable energy to 20% of total consumption by 2020. In addition, the European Union has set an indicative objective to reduce its primary energy consumption by 20% compared with the projected 2020 energy consumption. This stresses the need to increase energy efficiency in the EU. However, until now there has been no common methodology on how to measure energy efficiency or evaluate the savings achieved by it. The research project **"Measuring and potentials of energy efficiency (EPO)"** was launched in January 2008 to facilitate development in this field. The main objective of the research was to develop a general approach to measure energy efficiency. Furthermore, the research aimed to develop an approach which could be used to calculate the potential achieved by improved energy efficiency. Measuring energy efficiency and potentials are connected closely to each other in the sectors of energy production and distribution, industry, buildings, communities, transportation, and logistics. This report is a state-of-art description and a summary of the research findings in buildings, communities and energy systems made by VTT.

Energy systems consist of many energy chains or routes, which include alternative energy sources and process technologies, distribution and storage systems and end use equipments using electricity and producing, heat, light or movement. Almost all energy sources utilize many alternative routes, which may bifurcate and join together again on the way to the end user.

Energy efficiency in different energy chains was investigated in batch-surveys on the energy sector. Technical possibilities in energy chain have been evaluated for scenario calculation of energy saving potential in the future. Efficiency im-

pacts to primary energy demand were also evaluated. Emissions of different energy production ways give the value for environmental impacts and further the impacts of making more effective energy chains. A calculation model was made called “EPOLA”, which is used with scenario technique to analyse impacts of making more efficient national energy chains and to find out the most efficient ways to realise them.

Energy production chain has many indicators, which can be presented in consumption/produced-MWh that is one produced energy unit needs fuel, transportation, service, and human resources as well as transfer losses, emissions, and wastes. Indicator of quality of products, availability, reliability and on-peak period has to be present in another way. Indicators during building like material/produced-MW that is one built power unit needs materials like concrete, steel, copper, plastic, glass, etc. Energy is also required when building. The indicators of driving and building can be compared to each other in different energy production alternatives or to make bench marking with same kind and age energy production somewhere else.

Energy use in communities (city regions, cities, towns, and other urban areas as well as rural communities) takes place in both buildings and infrastructure, during construction, use, maintenance, repair, renovation, demolition and recycling as well as during transportation of people and goods. That is why energy efficiency of communities must be a composition of energy used during the life-cycle of several physical elements brought together for the community. Energy efficiency of communities can be defined as a ratio between an input of energy consumption or emissions, and an output of services, such as number of inhabitants and jobs or floor square metres. There are several energy efficiency indicators which consist of different parts and phases. Indicators complete each other. System boundaries for measuring energy efficiency of communities can be defined on the grounds of planning levels and areas or from functional bases. Communities may have a relatively high potential for energy efficiency improvements. Potential seems to be highest in the operation phase of structures and in transportation.

Buildings have a relatively high potential for energy efficiency improvements compared to other sectors of the economy. Indicators are needed to measure both current energy efficiency and improvement potential. Various indicators serve different purposes and interests in the buildings sector depending on the needs of the indicator’s user, who may range from the user of the building to the regulator, just to mention two of the typical stakeholders of a building. Defining a universal indicator to cover all needs is not possible. Therefore an array of indicators is suggested – what indicator to use depends on the situation and the objectives of the analysis.

Calculating energy efficiency potential is dependent on the scale and timeframe of the analysis. With small changes it suffices to take into account all significant energy flows and embodied energy with average primary energy coefficients. A profitability calculation should also be made. With large changes that entail systemic effects the primary energy coefficients should take marginal values. Systemic changes should be analyzed with e.g. scenario analysis and economic effects should be evaluated with e.g. economic modelling. Externalities and the rebound effect should also be considered.

Preface

This report is a part of the project "Measuring and potentials of energy efficiency (EPO)" led by Aalto University School of Engineering. The report has been made by VTT and financed by Tekes and VTT. The project was started in 2008 and will be finished in 2011. This report is a result of working during two first years and it concentrates on the results of energy efficiency in buildings, communities and energy systems. The results concerning industry and logistics are presented in other reports.

The project was controlled by a management group which consists of representatives of the following organisations: Motiva Oy: Jouko Kinnunen (chair), Tekes: Mikko Ylhäisi, Ministry of Employment and the Economy: Sirkka Vilkamo and Pentti Puhakka, Ministry of the Environment: Erkki Laitinen, Ministry of Transport and Communications: Jari Gröhn, Academy of Finland: Saila Karvinen, Confederation of Finnish Industries EK: Mikael Ohlström, Aalto University School of Engineering: Pekka Ahtila and Mari Tuomaala, Tampere University of Technology: Hanna Kalenoja and Erika Kallionpää and VTT: Pekka Tuominen, Irmeli Wahlgren and Kari Sipilä.

The management group has assembled for a meeting ten times during two years. The group has taken part of discussions actively giving their own views to the project group of Aalto University School of Engineering, Tampere University of Technology, and VTT.

The work concerning buildings and communities was also guided by a special steering group with the following members: Erja Reinikainen, Granlund (chair), Kyösti Oasmaa, Leena Silfverberg and Ulla Soitinaho, City of Helsinki, Mikko Nousiainen, Pöyry, Pekka Kalliomäki, Ministry of the Environment and Erkki Aalto, RAKLI.

The members of the project group of VTT have been senior research scientist Kari Sipilä and research scientists Juha Forsström, Esa Pursiheimo, and Miika

Rämä (energy systems), senior research scientist Jari Shemeikka and research scientist Pekka Tuominen (buildings), senior research scientist Irmeli Wahlgren, chief research scientist Pekka Lahti, and in the early stages research scientist Minna Halonen (communities). The project group of VTT wishes to thank the management and steering groups for their views, opinions, and inspiring discussion during the project.

Kari Sipilä, VTT group manager

Contents

List of abbreviations and symbols

A	Area
BAT	Best available technology
BAU	Business as usual
CO_2	Carbon dioxide
CO_2 –eq. = CO_2-eq.t	Carbon dioxide equivalent
CON = CP	Condensing power plant
CHP	Combined heat and power plant
DHC	District heating and cooling
EEmC	Emission efficiency indicator of communities
EEnC	Energy efficiency indicator of communities
EEnEmC	Energy and emission efficiency indicator of communities
EEI	Economic energy intensity
EI	Energy intensity
EIU	Energy intensity of usage
EPI	Energy performance index
EPO	Measuring and potentials of energy efficiency
EU	European Union
Floor-m^2	Floor square metre
Floor-m^2_{useful}	Useful floor square metre

GDP	Gross domestic product
GHG	Greenhouse gas emissions
IEA	International Energy Agency
Inh	Inhabitant
IPCC	Intergovernmental Panel on Climate Change
KWh	Kilowatt hour
LCA	Life cycle assessment
MJ	Mega joule
MWh	Megawatt hour
p	Weighting factor for primary energy
Q	Energy
R	Rent
SEC	Specific energy consumption
SEC_{UR}	Specific energy consumption adjusted for utilization rate
Sq. m	Square metre
T	Time
UR	Utilization rate
toe	equivalent crude oil ton
u	Utilization rate
wp	Workplace

1. Introduction

1.1 Background and objectives

The European Commission implemented a strategy for Climate Action in 2008. According to that strategy, the Member States will reduce their collective greenhouse gas emissions by at least 20% and boost the share of renewable energy to 20% of total consumption by 2020. In addition, the European Union has set an indicative objective to reduce its primary energy consumption by 20% compared with the projected 2020 energy consumption. This stresses the need to increase energy efficiency in the EU. However, until now there has been no common methodology on how to measure energy efficiency or evaluate the savings achieved by it. The research project “Measuring and potentials of energy efficiency (EPO)” was launched in January 2008 to facilitate development in this field.

The research aims to develop a general approach to energy efficiency measurement covering the energy systems, process industry, buildings, communities, transportation, and logistics. A uniform terminology and a way of measuring is a prerequisite for the comprehensive evaluation of energy efficiency within each sector and between the sectors. In addition, the research aims to develop an approach that can be used to calculate the energy efficiency improvement potential. This is needed in order to prioritise the activities towards increased energy efficiency. Activities include national codes as well as the research needs. An approach for the calculation is also used to identify technologies and services that promote energy efficiency and energy conservation. At the same time, the vision of the energy efficiency market potential will be sharpened.

The research objectives can be summarised as follows:

1. To develop a common approach for measuring energy efficiency in the sectors of energy production, the process industry, buildings, communities, transportation, and logistics.
2. To develop an approach to calculate the potentials for improving energy efficiency.
3. Based on steps 1 and 2, to calculate the energy efficiency improvement potential.
4. To recognise the means and technologies that support energy efficiency, to propose national energy efficiency focus areas, and to establish a foundation for energy efficiency technologies. (Ahtila et al. 2009)

This report is a state-of-art description and a summary of the research findings from the energy, communities and buildings sectors made by VTT. The next phase of the EPO-project will be a Grande Case, which utilizes the results of this first phase of the project. The Grande Case will be located to a real city area (Kalasatama in Helsinki) for applying and testing the developed energy efficiency indicators.

1.2 Energy efficiency and other criteria considered

The research objective is to establish a way of measuring energy efficiency. Energy efficiency can be defined as a ratio between an output of performance, service, goods, or energy, and an input of energy (European Commission 2006). On the other hand, energy efficiency is closely related to environmental factors seen as a subset of the eco-efficiency. A typical feature arising from the perspective of eco-efficiency is the amount of waste related to energy production and use. Indicators arising from the field of eco-efficiency are such as CO_2, NO_X, SO_2.

Measuring energy efficiency is a part of a wider context (Figure 1). Increasing energy efficiency is not an intrinsic value but a means to gain other wider goals. When measuring energy efficiency also other points of view should be considered.

Energy efficiency can be defined as a part of eco-efficiency. Eco efficiency is ecological efficiency that measures use of natural resources and disadvantages (negative impacts) in relation with results obtained. It can be defined as a part of sustainability. Sustainability covers ecological (or environmental), economic and social (including cultural and institutional) sustainability. Especially because of climate change the ecological sustainability is becoming more and more the hard core of the whole sustainability target. Eco-efficiency is a commonly used indicator measuring the ecological sustainability. Energy efficiency in turn represents the hard core of eco-efficiency, especially when non-renewable energy sources are considered.

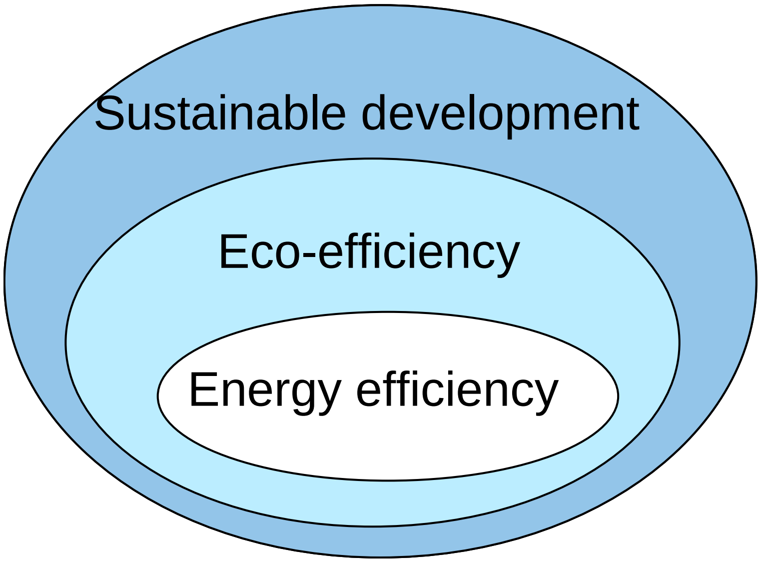


Figure 1. Energy efficiency, eco-efficiency and sustainability.

Together with energy efficiency, material efficiency may be measured (decreasing energy consumption may increase consumption of materials and vice versa).

Together with energy efficiency (kWh/product or service unit) it is possible to measure amount of emissions or carbon foot print generated by production and operation (e.g. CO_2-eq. kg/product or service unit).

In addition to energy efficiency, other changes in the study complex generated by energy production and use should be evaluated, e.g. on the community level quality of environment, on the building level quality of indoor air, in transportation accidents and noise, in industrial production coziness of working environment, safety etc.

Assessment of the complex requires at least presence of the next factors: energy efficiency, material efficiency, relative amount of emissions and wastes (may also be included in previous factors), quality of environment and life as well as costs (Figure 2).

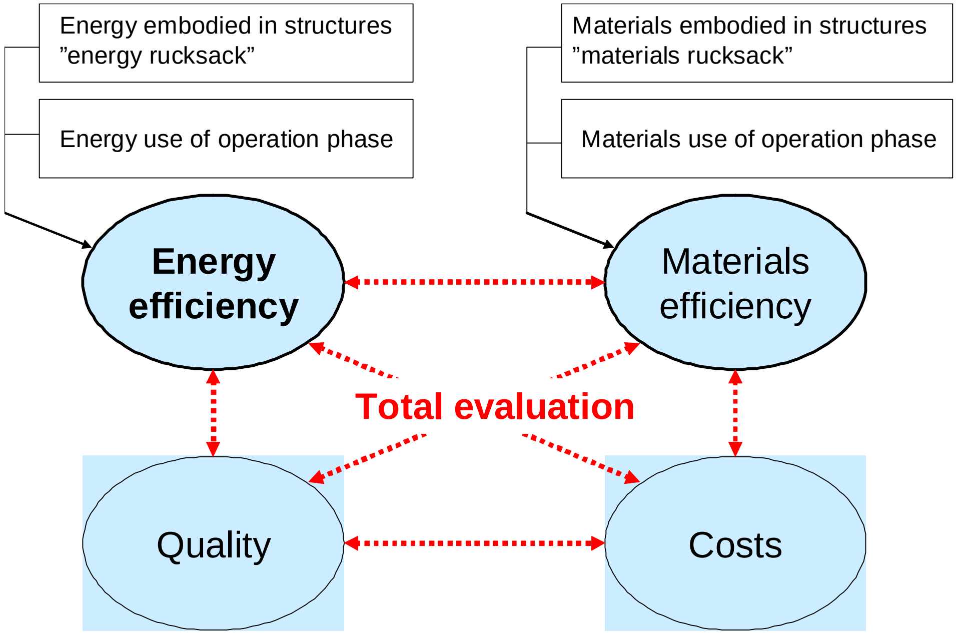


Figure 2. Energy efficiency measurement as a part of total assessment. Assessment of relative amounts of emissions and wastes (recycling included) is included here in energy and materials efficiency.

This research considers energy efficiency and CO_2-eq. emission efficiency. Materials efficiency is considered only as connected to energy embodied in building materials. Quality and cost factors are mainly left outside the considerations.

2. System boundaries

The purpose of system boundaries is to separate the processes or phenomena of specific interest from the environment where they occur. Interactions within and across the system boundary are taken into account differently. When studying energy efficiency specifically, inside the system boundary losses are calculated explicitly, whereas outside the boundary they are included into the analysis with conversion factors.

Here three slightly different views are taken to analyzing the problem of energy efficiency, shown in Figure 3. The purpose is to cover the whole energy chain from the extraction of primary energy to the final use of the energy services by the consumer. *The energy efficiency of the energy system* is the first one of the three areas of interest. There emphasis is given to the various conversions that take place to enable the consumption of primary energy for actual energy services. The area of interest closest to the consumer is *the energy efficiency of buildings*, where the final conversions of delivered energy and the factors affecting final energy demand are examined. Finally *the energy efficiency of communities* is studied as the composition, organization, and behaviour of the community greatly affect energy efficiency.

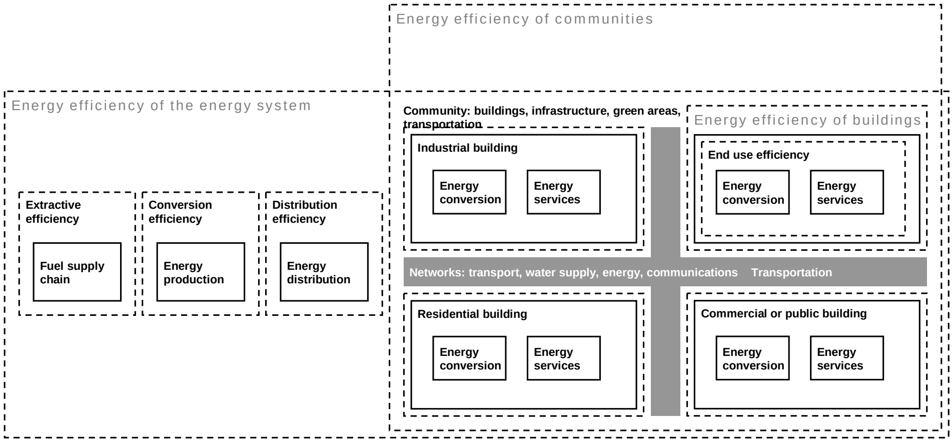


Figure 3. The overlapping system boundaries of the three areas of interest: Energy efficiency of buildings, communities, and energy production and use.

Well defined system boundaries are critical for making sure that the terminology used in the study is unambiguous and that the analysis is conducted consistently. Making the boundaries explicit ensures that, for each indicator, it is clear what inputs and outputs were considered and at what stage of the energy chain. Whenever energy flows across system boundaries, conversion factors can conceivably be used to describe the history of the energy flow upstream from the boundary. Such conversion factors must be coherently used throughout the whole system.

Furthermore, system boundaries allow the decomposition of end uses which is essential if one is to understand the phenomena explaining the changes in sectoral efficiencies. In terms of policy-setting and energy efficiency measures, the system boundaries have to be defined carefully to avoid partial optimization. The matter of system boundaries is discussed more in each of the sectoral chapters, especially under the titles *intersectoral interfaces*.

3. Principles for defining indicators

3.1 Energy efficiency

Energy efficiency is a term that is used in a variety of meanings in different contexts. Accordingly there is no one unambiguous quantitative measure of energy efficiency for all cases. The efficiency of energy conversions is commonly measured as the ratio of energy output and the energy input of the conversion process:

$$\frac{\text{Energy output}}{\text{Energy input}} \tag{3.1}$$

In processes where the output is not measurable as energy, the issue is more complicated. A measure has to be devised for the output that properly describes the service, process, goods, consumption, or need that causes the demand for the energy. USDOE (1995) calls such a measure a *demand indicator*. Indicators of energy efficiency in practical use often take the form of *energy intensity*:

$$\frac{\text{Energy input}}{\text{Demand indicator}} \tag{3.2}$$

Comparing with (3.1) one notices that intensity is inversely related to energy efficiency; that is, the greater the efficiency of a given process, the smaller its energy intensity. As energy intensity measures the rate of energy consumption per outcomes it answers to the basic question at the root of energy efficiency: how much must one consume energy to achieve the desired result? Also, it leads to the useful equation

$$Q = I \times S, \tag{3.3}$$

where Q is the energy consumption of an amount S of a desired service provided with an energy intensity I. For these reasons energy intensities of different types have become perhaps the most commonplace indicators of energy efficiency in use across the various sectors of the world economies (for example see IEA 1997, 2008, EEA 2000, APEC 2000, USDOE 1995, UNSD 2009, Motiva 2007).

The task of measuring energy efficiency may seem uncomplicated, contingent only on the choice of indicators for the input and output. In actuality, however, both can be measured in numerous ways and choosing one approach over another always leads to tradeoffs. Patterson (1996) has identified four main groups of indicators:

1. Thermodynamic indicators that rely entirely on thermodynamic quantities for both inputs and outputs (e.g. the thermal efficiency of a heating system).
2. Physical-thermodynamic indicators where energy inputs are measured thermodynamically but outputs have physical units (e.g. the energy consumption of a building per square metre).
3. Economic-thermodynamic indicators where the delivered goods or services (output) are measured in terms of market prices and energy in terms of thermodynamic units (e.g. energy intensity of the GDP).
4. Economic indicators that measure both inputs and outputs in monetary terms (e.g. energy spending per unit of GDP).

Each of these approaches has its strengths and weaknesses. Moreover, within each category there are numerous alternative indicators. For instance, even if one decides to use a thermodynamic indicator, a number of questions remain to be answered: Should primary energy be measured or delivered energy? Should one measure energy or exergy or both? If two outputs are produced, how should one allocate the energy consumed between the two?

Neither is choosing the right demand indicator simple. For example in cars the distance travelled is usually chosen: energy consumption in the form of fuel consumption is commonly measured as litres per 100 km. The distance is not, however, the only thing that affects fuel consumption. The mass of the car and the load affects the consumption too, as do driving habits and conditions on the road among other things. For perfect comparability all factors should be included in the indicator, which is arguably impossible. Thus all indicators are in general approximations of true energy efficiency.

Naturally the question most central to the formation of indicators should be: in what purpose will the indicators serve? In the case of a building, for instance, the designer, the builder, the user and the regulator all have differing objectives and interests and, therefore, can conceivably have use for different indicators. Similarly, a different indicator will serve best when environmental, social, economic, or other aspects of energy efficiency are considered. Moreover, an indicator describing a single building can radically differ from an indicator designed for the whole building sector.

Generally, in measuring the energy inputs the following issues need to be addressed:

- Life cycle. How to take into account energy consumed in the energy chain, embodied energy in materials, and energy recovered from recycled materials.
- Value of energy. How to accommodate different values of different kinds of energy, be they of a physical nature such as the ability to do work or of an economic or some other nature.
- Process integration and co-production of energy and the ensuing allocation problems.
- Reference values when benchmarking or potential calculations are wanted.

Measuring output requires addressing the following issues:

- Quality of the service or goods produced as this usually cannot be taken into account with the simple measurement of physical production quantities.
- The role of load curves and time series, as the indicators have to accommodate different levels of consumption at different times.

Finally, when formulating the indicators, a choice has to be made between a small number of aggregate indicators that are quick to interpret but can also produce misleading results if vital information is lost in the aggregation and a large number of more detailed indicators that require more interpretation and valuation decisions from the user.

3.2 Life cycle

When measuring energy efficiency, inevitably the question of life cycle arises. Energy is consumed to produce goods or services, such as lighting, transportation, heating and all the things that we purchase every day. Before goods or services can be delivered to the consumer, a number of steps have to have been taken.

If one intends to correctly measure the energy inputs that any act of consumption requires, one must consider the manufacturing, raw material acquisition and waste management necessitated by that consumption. This is the problem, as presented in Figure 4, that the science of Life Cycle Analysis (LCA) attempts to solve.

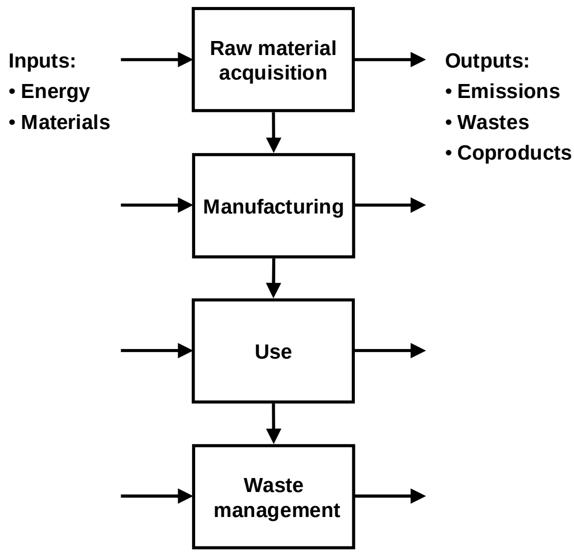


Figure 4. The classical view of the life cycle of goods in Life Cycle Analysis (LCA).

When energy efficiency is examined, the analysis is simplified because inputs other than energy can be excluded from the analysis to the extent that they do not contribute to energy consumption. On the other hand the task is made more complicated because for all energy inputs in any production chain the energy production itself has a life cycle not at all dissimilar from the one presented in Figure 4. In most cases raw material acquisition is required for the fuels consumed, and manufacturing can be equated with energy production (in a power plant etc.). Post-consumption waste management is not necessary in the sense as with material goods as all energy degenerates eventually into heat.

Hence the problem presented to the student of energy efficiency takes the form presented in Figure 5, whereby the consumer's own energy consumption is supplemented by the energy consumed for the material investments he or she makes (apartment, car, etc.) and consumer goods and services. Here the classical life cycle of products is presented as a vertical flow of investment goods, consumer goods and services to the consumer, and the production chain of energy is shown as a horizontal flow of energy. The matter is complicated further by the fact that a share of the consumer's wastes will go to recycling, potentially diminishing energy needs upstream, or to energy production as a refuse derived fuel.

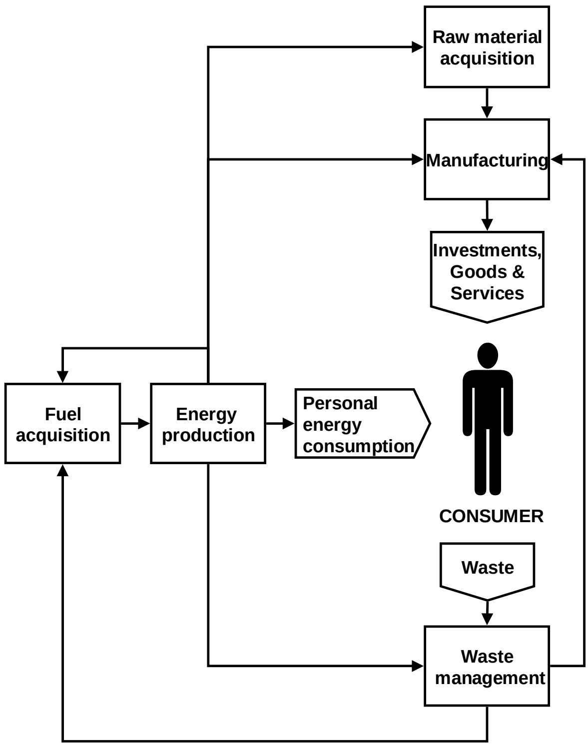


Figure 5. The vertical life cycle picture amended with the horizontal element of energy chain.

If it were necessary to tackle all the complexities of the energy system shown in Figure 5 to measure energy efficiency, the task would indeed be formidable. Fortunately LCA distinguishes between the foreground system, where explicit analysis of the system is necessary, and the background system where either average or marginal data for inputs can be used. In this study, the limit between foreground and background is demarcated by the system boundaries.

3.3 Value of energy

Value of energy can be defined as a content of energy resource measured e.g. (J/kg), (J/m^3), (toe/kg), (toe/m^3) or (primary energy/kg or /m^3) in certain temperature, pressure and humidity. A certain amount of energy resource is needed to do a defined amount of work.

Many factors have impacts to the value of energy. The most important factor is the purpose of energy use, what results can be achieved for individual or societal activities with minimum negative impacts to the surroundings, where we live. Time and place also have impacts to the value of energy. Sun shines mainly in summer and near the equator, but warming based on sun energy is needed in winter and Northern and Southern part of the globe.

The value of energy can be quantified:

- enthalpy or exergy value
- energy value of fuel based on upper or lower calorimetric value
- content of primary energy based on coefficients defined by EU
- toe, ton of oil equivalent
- CO_2 content of fuel (maybe also other emission components)
- price of energy
- marginal value of energy e.g. condensed coal power compared to average value of power
- investment value of energy source for utilising.

Other factors, which can have impacts to energy value and which can be changed according to time and place, are:

- renewable vs. non-renewable energy sources
- usability and transport of energy
- safety (risk for accidents)
- technical reliability of energy chain
- sustainability of energy source
- seasonal variation of energy demand
- dependence or independence of energy import
- self-sufficiency
- life-cycle of production unit
- recycled material of production unit.

Value of energy is decreased through the whole energy chain, because part of the energy will be lost in every phase. Net energy i.e. energy value is raw energy value multiplied by a serie of efficiencies in refining, production, and delivering process.

$$E_{used} = \Pi_{i=1}^{n} \eta_i E_{raw\,energy} \tag{3.4}$$

where η_i is efficiency of phase(i) in energy chain.

Changes of energy efficiency to the whole energy systems can be defined phase by phase, if all of those effciencies are known. Energy price will increase through the whole energy process chain because of decreasing amount of energy.

Combined heat and power (CHP) production or multiproduction including also cooling energy, water production or other fuel production makes the value of energy complicated, concerning what part of raw energy is to be allocated to every production component. Energy value divided to components can be evaluated by energy principle. Enthalpy or exergy value of energy is divided into products in relation to the energy value drop of each phase of components as a function of temperature and pressure.

3.3.1 Energy method

Energy method finds a connection between used fuel and final product (P, H).

$$X_p = \frac{(h_1 - h_2)}{(h_1 - h_6)} \tag{3.5}$$

$$X_h = \frac{(h_2 - h_5)}{(h_1 - h_6)} \tag{3.6}$$

Energy factor to power and heat

$$K_p = \frac{X_p Q_f}{P_G} \tag{3.7}$$

$$K_h = \frac{X_h Q_f}{Q_h}, \tag{3.8}$$

where P_G is power output, Q_h is DH output and $Q_f = Q_b/\eta_b$ is fuel effect, η_b is boiler efficiency.

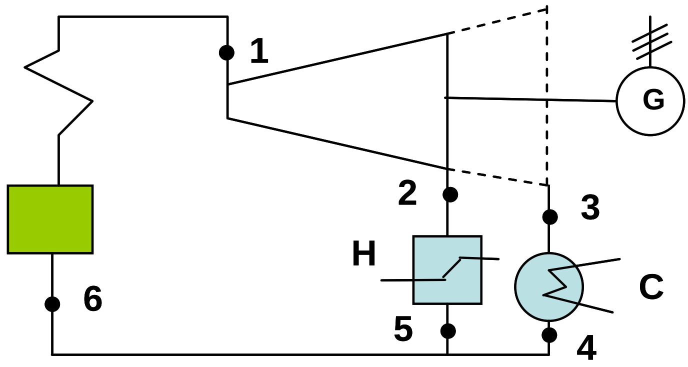


Figure 6. Principal scheme of Power plant (CHP, CP).

3.3.2 Benefit allocation method

Benefit allocation method takes into consideration also the second law of thermodynamic. DH's benefits will be defined how much the steam would produce more electricity, if it is led to expand to saturation pressure. We can write the factors (Figure 6) as:

$$X_p = \frac{(h_1 - h_2)}{(h_1 - h_3)} \tag{3.9}$$

$$X_h = \frac{(h_2 - h_3)}{(h_1 - h_3)} \tag{3.10}$$

If we have an intermediate power plant, the factors can be defined by measuring power in condensing mode $P_G(co)$ and power in back-pressure mode $P_G(dh)$ producing also district heat. The extra power is now

$$P_G(l) = P_G(co) + P_G(dh) \tag{3.11}$$

Therefore, the multiplication factors are

$$X_p = \frac{P_G(dh)}{P_G(dh) + P_G(l)} \tag{3.12}$$

$$X_h = \frac{P_G(l)}{P_G(dh) + P_G(l)} \tag{3.13}$$

and K_p and K_h are as in equation (3.7) and (3.8).

3.3.3 Exergy method

Exergy method defines the energy, which can be converted to mechanical work. The rest of energy is unenergy. When the system is in balance with surroundings, the exergy is zero. The exergy can be written as

$$e = (h - h_s) - T_S(S - S_S)\,, \tag{3.14}$$

where the index *s* means value of surroundings. Coefficients for power and heat can be written (Figure 6).

Exergy in the boiler:

$$E_B = e_1 - e_6 \tag{3.15}$$

and via the heat exchanger to DH

$$E_h = e_2 - e_5 \tag{3.16}$$

$$X_q = \frac{E_h}{E_B} \tag{3.17}$$

$$X_p = \frac{(E_B - E_h)}{E_B}\,, \tag{3.18}$$

which can be put into the equations (3.7) and (3.8).

3.3.4 Waste energy for primary energy to second hand process

Waste energy is invaluable to the ongoing process, but it is many times valuable to a second hand process, which is integrated directly or indirectly to a foregoing process. Multi-phase energy process is illustrated in Figure 7.

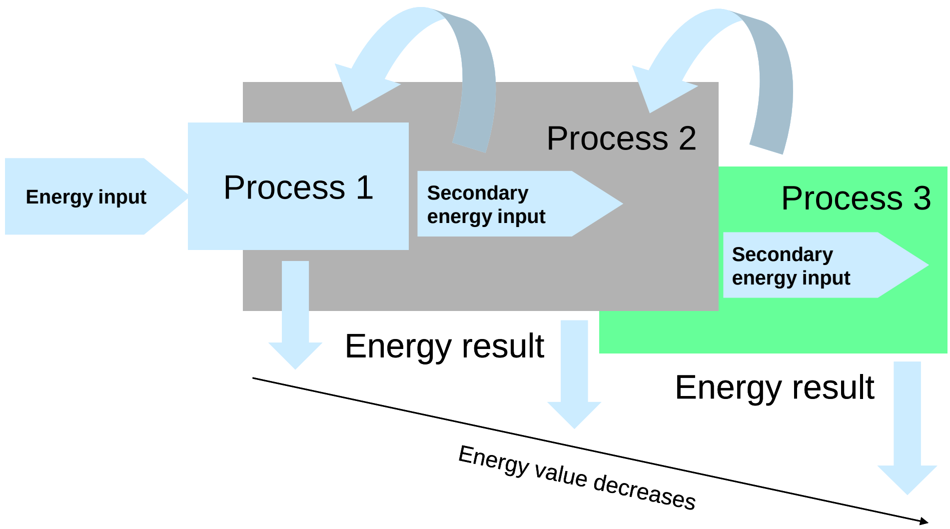


Figure 7. Multi-phase energy process utilises waste energy from upper energy level to second hand level.

3.3.5 Primary energy

Primary energy factor to different energy modes are defined in EN-15316 standard, where EN 15316-4-5 defines primary energy factor to district heating (DH). Calculation is based on fuel used in district heat production. The fuel energy of DH (incl. CHP production) is compensated by the amount of fuel, which would be used in separated electricity production equal to amount of electricity in CHP production. DH-production factor is

$$q = \frac{Q_{DH-chp \cdot e}}{H_{DH}} = \frac{Q_{DH} - E_{CHP} \cdot e}{H_{DH}}, \tag{3.19}$$

where Q_{DH} is fuel used in DH production including electricity in CHP plants
E_{CHP} is electricity production in CHP plants
H_{DH} is annual district heating production
e is electricity production factor for alternative electricity production (2.5 in EU).

If primary energy factor is wanted, Q_{DH} must change with Q_{prim}, which is the fuel energy converted to primary energy by the factor, which is typical to each fuel. Primary energy factor takes into account impacts of fuel to non-renewable energy sources.

4. Principles for evaluating energy efficiency potentials

Based on the first law of thermodynamics energy can not be created or destroyed. Energy is all the time in some mode somewhere. Energy just converts itself a certain amount between the system and the surroundings. The efficiency is in principle equal to one. Efficiency means in technique, how much products you can produce from certain amount of source; e.g. raw material in building sector and raw fuels in energy sector, etc.

4.1 Thermodynamic energy efficiency potential

Theoretically energy flows through energy conservation and transporting processes without causing any losses in energy chain. Practically energy conservation generates heat and part of it runs away outside the process because of e.g. friction and thermal convection of materials. If we compare the input thermal energy and output energy, we can define the thermal efficiency of the energy converted in process.

$$\eta = \frac{H_{out}}{H_{in}} < 1, \tag{4.1}$$

where H_{out} is useful energy output and H_{in} is useful energy input of the process.

The first law of thermodynamics does not take care of the quality of energy. Degradation of energy is taken care of in second law of thermodynamic, and evaluates the temperature difference between process and surroundings. The efficiency of Carnot cycle is defined as

$$\eta_c = 1 - \frac{T_{\min}}{T_{\max}}, \tag{4.2}$$

where T_{min} is the lowest and T_{max} the highest temperature in Kelvin degrees in the process.

When maximising the efficiency of the process the temperature difference $T_{max} - T_{min}$ must be as high as possible. As known the Carnot cycle efficiency is maximum theoretical efficiency, which can be achieved.

The useful energy can be defined as exergy (E), which evaluates also quality of energy. Then we put the exergy values instead of enthalpy (H) into the equation (4.1)

$$E = H - TS, \tag{4.3}$$

where T is temperature in Kelvin, H is enthalpy and S entropy in temperature T.

Theoretically energy efficiency potentials in systems exist in three spheres: theoretical, technical and economical. Theoretical energy efficiency represents the potential that exists theoretically. Technical energy efficiency represents the potential that can be reached using a known or commercial technology. Economical energy efficiency represents the potential that is achieved as economic criteria are applied. A distinction should be made between the three energy efficiency potentials. First of all, the difference between the theoretical and the technical efficiency illustrates the need for technical development. Then, the difference in the technical potential and the economical potential illustrates, which part can be affected by e.g. commercial development and legislation.

The energy efficiency potential can illustrated as in Figure 8.

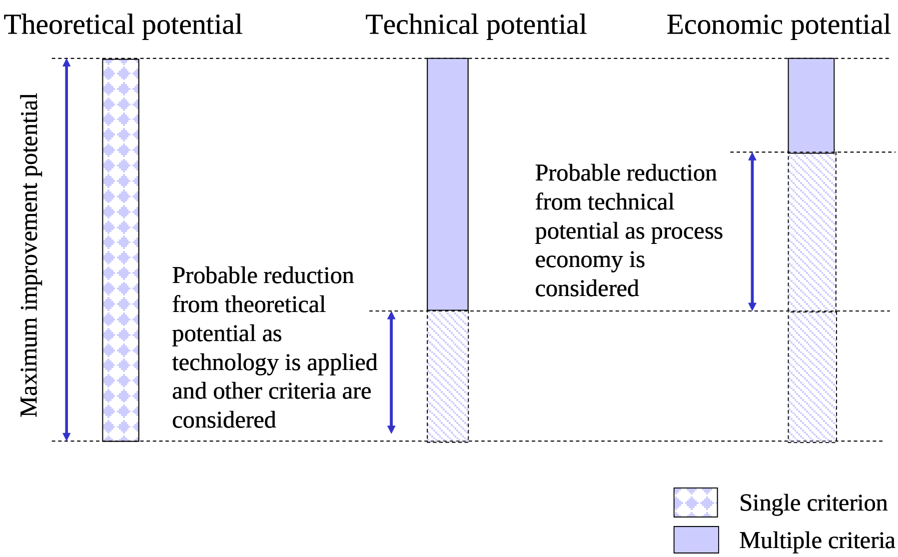


Figure 8. Development potential of energy efficiency in energy systems (Tuomaala 2007).

4.2 Technical energy efficiency potential

Practically all applications have losses in energy chain. Part of the raw energy is lost because of thermal convections through balance boundaries, friction of mechanical machines and flows, as well as incomplete chemical reactions. Also permanence of materials sets limits in conditions of the process as temperature, pressure, and chemical reactivity of energy media. The materials should be also able to sustain a reasonable time in use.

The maximum theoretical energy efficiency can be specified to describe the technical energy efficiency, which is achievable by using the best available technology (BAT) solutions, materials and process integration. Potential for improving theoretical and technical efficiency in energy chain is presented in Figure 9. Theoretical potential can be reached, if efficiency is equal to one in every point in the chain from fuel resource to end user. The analogical chain can be illustrated also for energy systems in buildings.

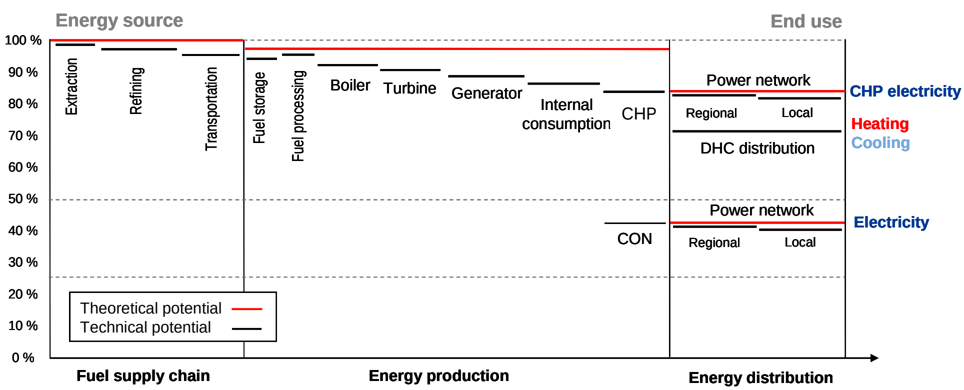


Figure 9. Potential for improvement of theoretical and technical efficiency in energy chain.

4.3 Economic energy efficiency potential

In economy perspective we look at energy efficiency in investments and using of energy in the system. A new technique competes with the existing technique and a requirement to get into market must be prevailed with better energy economy. Economical energy efficiency is many times a function of time, because a short utilisation time of the process limits the economy more than a long utilising time. This may reduce the technical energy efficiency that would be otherwise possible. The economic efficiency is often based on life-cycle cost efficiency.

The maximum technical efficiency can be as high as it is economically viable from the life-cycle cost point of view. In addition the investments already done in industry, in energy production, or in buildings define the highest efficiency that can be achieved by using certain technologies or solutions. To get a remarkable increase in efficiency, the whole technical solution should be replaced and barrier to make that investment might be too high.

The economic energy efficiency can be divided into business, macro-economic, and societal impacts. The business energy efficiency is seen as a financial perspective on the side of individual investor based on technical and economic life-cycle cost analyses. Only way to guide the investor to a new technology direction is financial support to investment, legislation, or a highly efficient solution in a life-cycle economic way. The investment must be done with an acceptable risk subject to discount rate and repayment period.

In macro-economic analyses we have to account direct and indirect economic impacts to national incomes, price level, employment rate, economic fluctuation and growth. Therefore direct administrative costs and indirect impacts of implementing policies to improve energy efficiency must be done. It means subsides, constrains and bans in practical policy.

Social impacts reflect the highest economic viable energy efficiency to avoid damages to the environment and health; that is, negative externalities. This means that integrating environmental impacts and sustainable society into energy economics as well as improving energy efficiency might be uneconomical in business and macro-economic sight, but it may be economical in the societal point of view. In other words, when the avoidance of externalities is included in the cost-benefit analysis, a higher investment cost is justified.

Energy production entails rather large external costs, for some fuels some estimates put externalities even over 100% of the market price. A major externality of energy production is the aggravation of the climate change but other environmental effects can also have serious consequences. Including the externalities in the price of energy emphasizes the utility of energy conservation. (Hall 2004)

5. Buildings

5.1 Sectoral properties

The role of buildings in both world energy consumption and energy efficiency potential is central. Residential and commercial buildings consumed 38% of the world's final energy and caused 33% of its CO_2 emissions in 2005 according to the IEA (2008). If energy consumption is high in the buildings sector, so is the potential for savings. The IPCC (2007) and the European Commission (2006) are among the latest to uncover the greatest energy saving potentials in buildings compared to other sectors of the economy. This is especially true in terms of primary energy, as buildings are in the very end of the energy chain and, thus, all effects of efficiency improvements are multiplied in each conversion upstream. Understandably, ever since the energy crisis of the 1970's, the buildings sector has become one of the focal points for the efforts to increase energy efficiency. The residential sector in particular has had more energy-related policies put in place than any other sector in the IEA countries (Haas 1997).

The Finnish residential building stock is 270 million m^2 of which 55% are single-family houses, 33% apartment buildings and 12% row houses. Commercial and public buildings amount to 82 million m^2 of built area. District heating is the most commonplace heating source in Finland with a share of 43% of all heated area. Oil and electric heating share the second place with 22% each. Solid fuels such as wood and peat are used in 8% of buildings and the remaining 5% use other heating sources such as ground heat pumps. (Statistics Finland 2009).

Buildings consume energy directly for heating and cooling and indirectly through electricity for lights, appliances, office equipment, refrigeration, cooking and motors in pumps and ventilating systems. The energy system in a building required to perform the final conversion from delivered energy to useful energy services is presented in Figure 10. The figure also serves to define the two major system boundaries: the *building* itself that demarcates the limit where outside energy flows (fuels, district heat, electricity, and even direct sunlight) reach the building and the *indoor environment* where the actual energy services take place. Presently most buildings are only consumers of energy but the figure features also outflows of heat and electricity in anticipation of future micro-generation system.

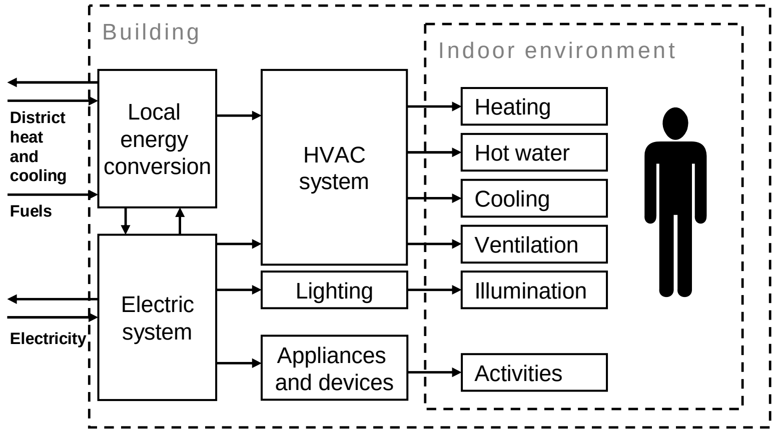


Figure 10. The system boundaries of a building.

It is worth noting that the occupant depicted in the picture on the right is solely interested in the consumption of these services – all of the actual systems shown in the figure on the left are subordinate to the provision of the energy services. Fundamentally the whole idea of energy efficiency is to provide the same services with less energy or better services with the same amount of energy. However, the interests and priorities in matters related to energy efficiency are different to different actors.

Energy efficiency indicators serve various purposes in the buildings sector depending on the needs of the user of the indicator. The most important stakeholders for a typical building are shown in Figure 11. Naturally all of these stakeholders have differing objectives and all are principally guardians of their own interests and all are interested in different things regarding energy efficiency.

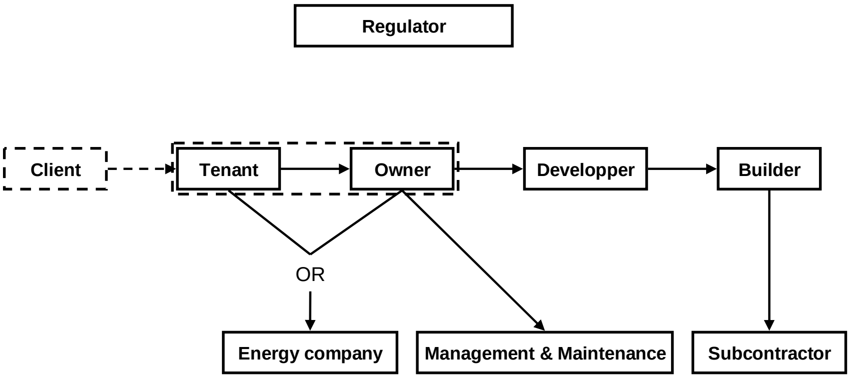


Figure 11. A customer relationships of some of the main stakeholders for a typical building. In some cases the tenant and the owner are the same. Regulator is understood to include all sources of regulation such as municipalities, the government, associations, etc. In residential buildings users naturally have no clients.

Figure 11 presents some of the interests of the various stakeholders regarding energy efficiency. Of course all of the stakeholders probably share some level of interest to all of the issues depicted but primarily their concern is directed towards the issues most relevant to their field of activity and especially profit. This patchwork of stakeholders' intersecting interests forms the framework where indicators of energy efficiency will be used.

Defining indicators to cover all needs, as presented in Figure 12, is a huge task and might not even be possible. It will be an ongoing process of improvement and adaptation to new needs and priorities. For instance in 1970's the priority would have been to minimize the need for imported fuels, currently the primary concern is climate change. In the future our objectives will, in all likelihood, differ from the present.

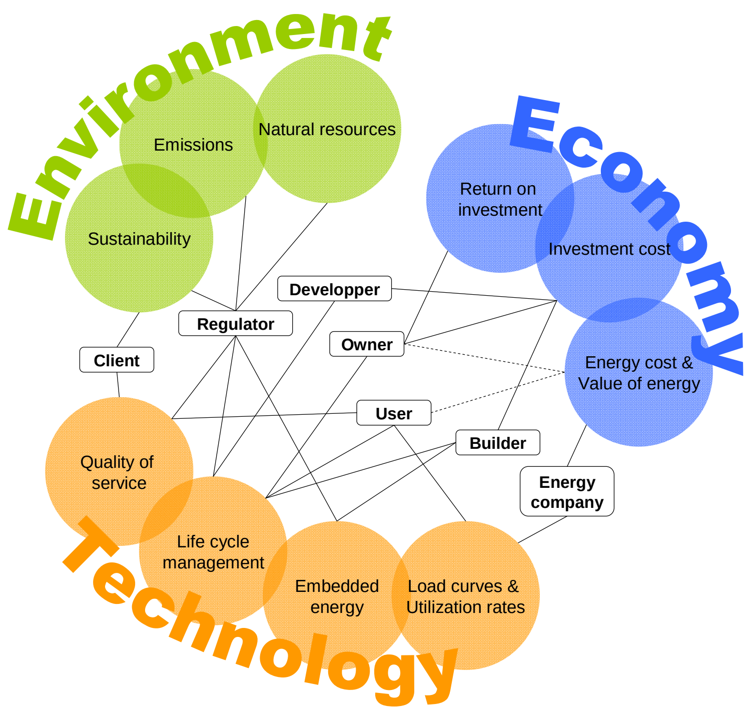


Figure 12. Examples of the primary interests of some of the stakeholders presented in Figure 11 with regard to energy efficiency. The level of interest of the owner and user towards energy cost depends on who pays for the energy.

5.2 Defining indicators

Considering the issues discussed in Section 5.1, it is clear that the present set of indicators – relying heavily on energy intensity of the built area and device-specific indicators – does not very well cover the multitude of factors important to the various stakeholders. It is therefore understandable that there is a great demand for new indicators. The mainstay of present energy efficiency indicators is the specific energy consumption of a building (compare with energy intensity explained in Chapter 3):

$$\frac{\text{Energy consumed}}{\text{Built area}} \tag{5.1}$$

One can devise ways to amend the equation to better reflect the different facets of energy efficiency. For instance, to take into account the life span aspect, one could add to energy consumed the energy embodied in the building materials and subtract the energy recovered with recycling. The utilization rate of the building could be taken into account with a factor in the denominator. This factor could vary from one (full use) to zero (not in use). Quality could be taken into account in a similar manner. In this case, an indoor environment with a perfect quality would be indicated with a value of one. An unacceptable indoor environment quality would theoretically be indicated with a value of zero; in practice, however, regulations would limit the quality factor to higher values. Thus the equation would become the following:

$$\frac{\text{Embodied energy} + \text{Energy consumed} - \text{Energy recovered}}{\text{Built area} \times \text{Utilization rate} \times \text{Quality factor}} \tag{5.2}$$

In reality, however, such an enhanced way of measuring becomes difficult to define. For example defining a life-span and taking recycling into account is complicated. Defining quality is another challenge as it is affected by such various factors as thermal conditions, air quality, lighting, sonic environment, water quality, quality of electricity supply, service and maintenance, etc., which are all measured in different ways. Their reduction to one figure would almost certainly lead to misleading results.

A more practical approach is to create a set of indicators, with each applicable for a different purpose. Any single indicator devised is unlikely to be able to cover all or even a significant share of all of the different interests and issues at play successfully, without loss of important data. Every indicator should be developed keeping in mind the specific use and objective that it is intended for. On the other hand, with a right combination of indicators it should be possible to adequately cover most of the essential aspects of energy efficiency in buildings.

In practice quality will have to be left out of the energy efficiency indicators, as its measurement is a very complex issue. There are already various indicator systems that include quality indicators, such as PromisE, and others are under development. It is strongly recommended that some evaluation of quality is carried out whenever energy efficiency is determined so that differences in quality will be evident when comparing the results.

5.3 Indicators of energy efficiency

As was explained before, the definition of indicators is an ongoing process. The indicators suggested here are not meant to be final, but rather the current view of the authors. No one indicator can cover all the aspects of energy efficiency.

Therefore a set of indicators is suggested with each indicator being able to capture some facet of energy efficiency better than the others.

The indicators chosen are an attempt to strike a balance between the different aims of (1) coming as close as possible to an accurate description of the energy efficiency of a building while (2) satisfactorily covering the different aspects of energy efficiency important to the various stakeholders and making sure that (3) the indicators are practically applicable and (4) the necessary data is reasonably available. Using a combination of indicators is necessary to get a complete picture of the energy efficiency of a building. What indicators to use depends on the situation and the objectives of the analysis.

5.3.1 Measuring Energy Consumption

All of the indicators include the quantity Q, which is defined as the energy, in kWh, consumed annually or some other given time period in the building or buildings under consideration. In current practice Q usually includes at least all commercially delivered energy to the site (commonly called just *delivered energy*). In some cases some local energy sources are counted in, such as firewood. Sunlight and ambient heat utilized by heat pumps is almost never included probably because they have no alternative economically viable uses. This is good, as the use of resources with no alternative use or environmental importance should indeed be encouraged by the indicators. On the other hand, firewood and other scarce resources should be included in Q when measuring energy efficiency, even if they are free, to promote their economization. At the minimum, an explicit listing of what is and is not included in Q should be provided when applying the indicators.

Presently in almost all cases all useful energy flows are inbound to the building. In future, however, it may be the case that some useful energy flows also leave the building. This requires no major amendments to measuring Q, as it can simply be taken into account with negative numbers.

Moreover, a thorough analysis of energy consumption should take into account the energy consumed and possibly saved in the construction, renovation and dismantling of the building. The presently common practice of concentrating only on the energy consumption of the building's use gives in most cases a sufficiently accurate approximation of the total life-cycle energy consumption of the building as the significance of the other phases is relatively small. However, as the energy efficiency of buildings improves over time, it can be expected that the relative importance of life-cycle energy usage increases to the point where it cannot be ignored any longer.

There are methods to calculate the embodied energy content of building materials, including the effects of their recycling in the end, and these figures are commonly available in various publications (see e.g. Hammond & Jones 2007). To make embodied energy commensurate with delivered energy, it has to be annualized. This is achieved simply by dividing the total embodied energy of the building with the expected life-time of the building.

Finally, the question of value of energy has to be addressed. As was explained in Section 3.2, different types of energy have different values in many senses. Different forms of energy have different prices. High exergy energy carriers have more uses than low exergy alternatives and are thus more valuable. For any given flow of delivered energy a long energy chain has been necessary – the actual primary energy consumption can be many times higher than the consumption of delivered energy.

For buildings the energy chain prior to the building site is outside the system boundaries defined in Section 5.1. Therefore, the value of energy should be taken into account with a factor p applied to different energy flows $Q_{electricity}$, Q_{heat} and so on. The value of p can reflect the monetary, exergetic, GHG, primary energy or any other value of the various energy flows. It is critically important that the energy flows with different values are not summed before they have been weighted with the factor p. Thus the equation for Q becomes

$$Q = p_1Q_1 + p_2Q_2 + \dots, \tag{5.3}$$

where Q_1, Q_2, etc. are the various energy flows of different values, including annualized embodied energies, and p_1, p_2, etc. are the respective value of coefficients. When weighing heating and cooling energy, p can include, when relevant, a normalization factor for climatic conditions. The choice of the proper method for such normalization depends greatly on the climatic variance in the data at hand and should be done at a national level (for Finland see Motiva 2009).

5.3.2 Specific Energy Consumption

The specific energy consumption (SEC), already introduced in Section 5.2, is a simply formulated, easily interpreted, general purpose energy efficiency indicator for buildings. It is defined as

$$SEC = \frac{Q}{A}, \tag{5.4}$$

where A is the area under consideration in m^2. Typically A includes either the heated area of the building or all of the built area. Including only the heated area has the benefit of better describing the efficiency of heating in the building. On the other hand keeping some areas of the building, such as storage, without heating can in itself be seen as a energy efficient practice that perhaps should be rewarded in the measurement. Nevertheless, in most cases the former practice gives a clearer picture of the actual technical efficiency of the structure. Some have also argued for using volume instead of area. This may be justifiable in some cases, but in most buildings area gives a clear enough picture of energy efficiency and the data is more readily available.

SEC is already widely in use, which enables comparisons nationally and internationally. Also data for it is usually relatively easy to obtain. It is also easy to understand. Even though it has some weaknesses, such as the exclusion of utilization rate and economic factors, it is recommended that it remain in use, in combination with other indicators, to ensure temporal and regional comparability of data.

5.3.3 Specific Energy Consumption Adjusted for Utilization Rate

The energy usage of buildings consists of the base consumption that takes place regardless of the actual use of the building and of the user's energy consumption. Since the base consumption, consisting of heating, minimum ventilation and other continuous energy services, runs regardless of the usage of the building, energy efficiency can be improved by increasing the utilization rate of the building. An added benefit is that this can counter the need for more built space. Let us consider for instance a school gym: if it is used after school hours for sports, the need for a separate gym building might be averted. The matter is discussed further in Section 5.5.

SEC can be modified so that it allows for different utilization rates of the building. Recalling the equation for energy intensity from Section 3, useful outputs should be measured in the divisor. It is therefore suggested that SEC be adjusted for utilization rate (UR)

$$SEC_{UR} = \frac{Q}{uA}, \tag{5.5}$$

where u is the utilization rate of the building which, in turn, can be defined in different ways. The most obvious way is to measure the ratio of actual daily usage hours T_{actual} to the highest possible usage hours T_{max}:

$$u = \frac{T_{actual}}{T_{\max}}\ , \tag{5.6}$$

T_{max} is at highest limited to 24 hours per day, but in some cases there are other practical limitations. For instance night hours can reasonably be excluded for office space and most other commercial and public spaces. One can devise other more complicated ways to measure u, such as the ratio of number of person hours (cumulative number of hours spent by various people in the building) to the highest possible number of person hours. These can be necessary in some cases, but another alternative to SEC_{UR} is discussed next.

5.3.4 Energy Intensity of Usage

SEC_{UR} is an indicator that takes into account both the area of the building in question and its utilization rate. One can, however, argue that SEC_{UR} does not take into account more efficient use of space. Let us consider two office buildings of similar size but one has 10% more people working because storage rooms are arranged more efficiently. Still both would get the same rating with SEC_{UR}. Basically, because the area of the building is in the divisor, SEC and SEC_{UR} do not effectively reward more efficient use of space. Therefore it is suggested, that an indicator should be devised that measures simply the amount of energy consumed per person hours (T_{pers}) spent in the building, namely energy intensity of usage:

$$EIU = \frac{Q}{T_{pers}} \tag{5.7}$$

This indicator highlights the energy usage per user aspect on buildings, and is especially good in measuring the efficient use of space. On the other hand its comparability between different types of buildings is not very good and the effects of tightly packed work or living environments on the quality of the said environments can be discussed. Therefore, as with all the other indicators, it is strongly recommended that quality be also measured with a proper but separate system of indicators.

5.3.5 Economic Energy Intensity

In Section 3 economic-thermodynamic indicators were discussed. They were defined as indicators where the output, delivered goods or services, is measured in terms of market prices and energy in terms of thermodynamic units. Whether this sort of indicator can be developed for buildings depends on whether the value of the building to its user has a monetarily measurable market value. Rented buildings clearly have such a value: rent. Owner-occupied buildings also have a market value when sold. At other times defining the value may be difficult, but it can be estimated by comparing similar buildings' sales prices and rents. Some types of buildings, especially some public buildings, are very seldom sold, and they are perhaps the trickiest to value. In their case a rough estimate can be used or economic indicators can simply be left out of consideration.

In well functioning real-estate markets there should be no difference between the costs of owning and renting a building. Rent simply should cover all the costs associated in owning the building, including capital costs, risks, and maintenance among others (KTI 2010). Therefore it is suggested that rent or the rent level of buildings of similar value should be used as a basis for estimating the economic value of the building. Thus the building economic energy intensity (EEI) is defined as

$$EEI = \frac{Q}{R}, \tag{5.8}$$

where Q is energy consumption for a given time and R is the rent in € payable for the same time.

What do we learn by studying by such an indicator? The rent gives a minimum value to the utility of the building to the tenant. If the tenant felt that he or she paid more for the building than he or she benefits from it, he or she would not stay in the building. Thus the *EEI* gives us the unique ability to compare the energy consumption to the utility derived from it. A further benefit is at least some level of comparability with other sectors.

A consequence of the definition of the *EEI* is that higher rent with similar levels of energy consumption means higher energy efficiency even in similar buildings. Does this make sense? In a strictly physical sense such a result may seem nonsensical. From an economic point of view, however, people have to have some motivation to pay higher rent. They perceive a higher level of utility, be it due to location, services, scenery or whatever. If with same level energy consumption people can be given a better, more valuable output, then surely that is, by definition, more energy efficient.

The classification in Section 3 would label *EEI* as an economic-thermodynamic indicator. To make it a pure economic indicator energy consumption should also be enumerated in monetary terms. This can be done by using a value coefficient *p* that reflects the prices of the different energy flows, as was explained in the Section 5.3.2. This could give a more accurate reflection of the sensibility of consuming energy as an economic resource in the building, compared to the useful output produced, provided that energy prices reflect energy supply and demand forces. It would also at the same time provide the user with data about the significance of energy in the housing spending.

Finally, it should be noted that not nearly all of the energy consumed in buildings is consumed by the building itself. A large share of the energy is consumed by the activities taking place inside the building. In businesses these activities infer costs and generate value that is not included in the rent. For businesses, therefore, it might make sense to use a measure of the value generated by the energy consumption rather than rent for *R*, especially if the activities are energy intensive. However defining what share of the value added is due to energy consumption rather than other factors of production (capital, labor) is tricky. For energy intensive businesses *EEI* may thus be an impractical indicator.

5.3.6 Energy Performance Index

Benchmarking indicators are required to assess energy saving potentials, something that the other indicators do not show explicitly. Therefore an energy performance index (EPI) is suggested, defined as follows:

$$EPI = \frac{Q_{actual}}{Q_{BAT}}, \tag{5.9}$$

where Q_{actual} is the actual energy consumption of the building and Q_{BAT} is the energy consumption of a similar building applying best available technology. Clearly, an indicator of this form will show values greater then one when technology allows energy efficiency improvements. The greater the value of the indicator, the greater the technical saving potential is.

BAT is understood here as a technology already available from the markets that could reasonably be applied with cost-effective investments. At this stage such technologies are net energy consumers on the level of the whole building.

If at some point best available technology advances to the level of energy-plus-houses, the equation would yield negative figures for actual buildings that consume energy. This is not a problem, but should be remembered in interpretation. If Q_{BAT} is zero, *EPI* is undefined.

5.3.7 Choosing and Applying the Indicators

In general, the choice of indicators should be based on thoughtful goal definition: why energy efficiency is measured? What decisions are informed by the indicators? Examples of possible topics to be addressed in the analysis are shown in Table 1. This should be coupled with scoping of the analysis at hand, including decisions about system boundaries and how much of the energy chain is included.

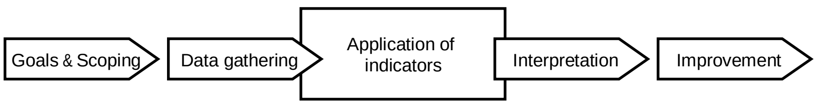


Figure 13. The process of applying the indicators.

In addition to the indicators defined here, the use of other indicators that may suit better in some specific cases is encouraged. In some buildings a single device or process consumes the bulk of all energy; consider, for example, a hockey arena where refrigeration eats up a huge portion of the energy consumed. There it makes sense to measure separately the efficiency of the refrigeration apparatus. More indicators for use in buildings and building components have been published for instance in the RET project (Heljo 2005).

Table 1. Including desired topics into the indicator set at the goals and scoping phase.

Examples of topics to be covered	**Methods for inclusion into the indicator set**
Environment	Environmental p-factors, EPI
Economics	Monetary p-factor, EEI
Improvement potential	EPI
Efficient use of space	EIU, SEC_{UR}, EEI
Life Cycle	Annualized embodied energies in Q
Quality of service	Measured separately

Then the necessary data should be gathered, including all energy flows included and embodied energies included in the scope of the analysis. When the indicators are applied to the data, the results should be interpreted to understand the meaning of the figures. Finally, opportunities for improvement should be recognized. This recommended process, presented in Figure 13, is based on the established methodology of LCA (see e.g. Guinée 2002), which can be used here to the extent that it is applicable.

5.4 Intersectoral interfaces

Buildings are a relatively well-defined entity in the field of energy efficiency studies, with clear boundaries with the surroundings and a limited number of energy in and outflows. Many aspects of the study of buildings are, however, dependent on other sectors. In some cases a more broad analysis than one limited to the boundaries of Figure 10 is called for. The following sectors have the greatest level of interfacing with buildings:

- Construction sector. Buildings embody a significant amount of energy in building materials. To determine the amount of this energy the construction and building materials industries have to be studied. Naturally, their energy efficiency can also be improved, which will bring down the amount of embodied energy. Fortunately there is a lot of data already available due to studies made for LCA and in most cases the use of average figures is quite sufficient. Building specific calculations are necessary if unique or novel construction methods, materials or recycling are used.
- Communities and transportation. Buildings have a major effect on the energy consumption of the society but of major importance is also how buildings are situated, connected and used. To give some examples having jobs and services close to home and a good public transportation system greatly reduces energy consumption for travel. Working at home and shopping online does the same and also reduces overall energy consumption in buildings because less commercial space is needed. Therefore, for a full picture of energy efficiency, the study of communities is crucial.

- Energy sector. The meaning of energy chains to the analysis of energy efficiency was already explored in Section 3. In short every energy carrier has a long energy chain of deliveries, conversions and fuel acquisitions behind it before it can be consumed. To determine how much primary energy is consumed for each unit of useful energy, these chains have to be studied. Again, in most cases, the use of average values is sufficiently accurate for the analysis of single buildings.

Even though in most cases using average figures to account for processes outside the system boundaries of buildings, expanding or rather adding system boundaries to the ones shown in Figure 10 may be necessary in some cases. These include:

- When there is a unique energy system serving the building or buildings in question. For example if a local heat plant serves a group of buildings, then of course figures for that plant, rather than average figures, should be used in the analysis. Moreover, if the changes expected in the building or buildings are significant enough to affect the operation of the plant, this should be taken into account too.
- When changes are expected in a very large portion of the buildings in the society. This will be enough to affect the whole energy system. In short term *marginal* rather than *average* figures represent better the changes in primary energy and GHG coefficients. In long term it should be assumed that the energy system will adapt to changes in demand; this can be taken into account e.g. with scenario analysis.
- When specialized techniques or materials are used in the construction of the building, the effect of these on embodied energy should be analyzed.
- When the building is used in an atypical way that can be expected to lower energy demand in other buildings that should be included in the analysis. For example, if the building is designed so that the occupant can do at home work that previously required a separate office, the energy savings from not needing that office space anymore should be included.

In general, whenever major changes outside the building system boundary are expected that would not otherwise occur, those changes should be included.

5.5 Load curves and partial loading

As is shown in Figure 14, the energy consumption of a building consists of the base consumption that takes place regardless of the actual use of the building and of the user's energy consumption. The base consumption is caused by heating, ventilation, pumps, some forms of illumination, and other continuously running energy services. The user consumption is caused by all the various activities that people engage in inside the building, such as using lights, appliances, and electronic devices, and also changes in the mode of operation of some automated systems, such as air conditioning and ventilation.

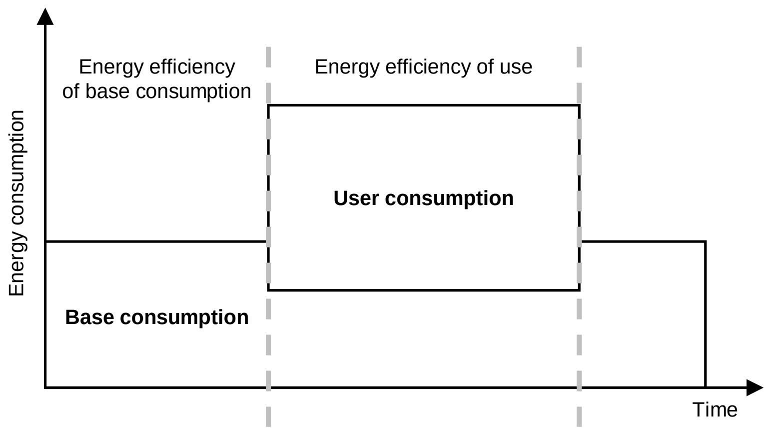


Figure 14. The roles of base consumption and use in the energy efficiency of buildings.

Changes in energy consumption loads have an effect on energy efficiency. On the level of the building, increasing the utilization rate can be used to improve efficiency, as the amount of pure base consumption with no useful output is diminished. This can be taken into account in the indicators, as was discussed in Section 5.3.3. Moreover, the capabilities of the energy system have to be sized to match consumption levels and specifically peak consumption. Levelling consumption peaks, so-called peak shaving, is inherently efficient as, in the short run, the use of the usually most inefficient peak power infrastructure is avoided and, in the long run, as the need for investments in energy infrastructure may be avoided.

5.6 Examples of potential evaluation

5.6.1 Potential evaluation for an apartment building

The indicators suggested in Section 5.3 were tested on cases of simulated 3-floor apartment buildings in Helsinki. Another aim was to show how much energy could be saved by employing passive house technology in an otherwise typical building. The software used for the simulation was WinEtana 1.1, published by VTT in 2003. Two different kinds of buildings were studied, both identical with 1146 m^2 in 17 apartments and 28 occupants, heated with district heating, except for the following properties:

Building 1:

- Built according to the presently applicable building code from the year 2003.
- Average electrical appliances and devices.
- Average water consumption.

Building 2:

- Built as a passive building.
- EU energy efficiency class A electrical appliances and devices.
- 30% efficiency improvement in hot water consumption.

Also studied were two ways of using the buildings: one with working people, leaving the building unoccupied for long periods during the day, and the other with elderly people, who stayed most of the day inside. The former way is labelled A and the latter B, yielding in total four simulated circumstances: 1A, 1B, 2A and 2B.

The indicators applied to the buildings were the ones presented in Section 5.3: specific energy consumption (SEC), specific energy consumption adjusted for utilization rate (SEC_{UR}), energy intensity of usage (EIU), economic energy intensity (EEI), and energy performance index (EPI). For EEI, average rent from 2008 was used. Primary energy factors were the ones suggested by the IEA for use in the EU (Hastings 2008). The results should be seen only as examples and not representative of any actual building; they are presented in Appendix A.

For SEC the tables show that the results are as expected, considering that it is a measure already commonly in use. Figures around 200–300 kWh/m^2 are quite typical for new buildings and passive technology has the potential to halve the energy consumption. SEC_{UR} clearly favours B cases where people spend more time in the building and the same effect is manifested even more clearly with EIU which has no area component at all. EEI provides results that are in this case identical to SEC in relative terms, as all the buildings are assumed to have the same rent level. If this was not the case, different figures would have ensued.

Finally, EPI shows that the regulation building has 53% room for improvement in annual consumption of delivered energy and 39% when embodied energy and primary energy consumption are considered compared to best available technology, assumed here to be a passive building. The smaller energy efficiency potential in the latter type of analysis is explained by the slightly higher amount of embodied energy in the passive building and the low primary energy weight of district heating, where the greatest savings are accomplished.

5.6.2 Potential evaluation for space heating in the Finnish building stock

In course of the EPO project a Master's thesis concerning the heating energy conservation potential in the Finnish building stock was completed. A summary of the results is published here. A more detailed description, including evaluations of the investment costs, economic effects, externalities, and the rebound effect of energy consumption, is available in the thesis (Tuominen 2008).

Estimates of heating energy conservation potentials are given for two scenarios: one anticipating slow and the other quick development in low energy buildings in the Finnish building stock. Residential and commercial buildings are included in the study; industrial, agricultural, and some other minor categories of buildings are excluded. The estimates are based on a business as usual (BAU) scenario that anticipates the continuation of current construction practices. The scenarios are defined as follows:

- Business as usual (BAU) assumes that buildings continue to be built according to current practices. The results of the other two scenarios will be compared to this one to quantify the savings potential and the consequences of its realisation.
- Delayed development (DD) assumes that the share of low energy buildings will gradually increase so that by 2030 most new detached houses are low energy houses whereas among the rest of new construction low energy buildings will achieve similar market penetration ten years later. Passive buildings will become the norm much later, in the

2070's and 2080's. Furthermore, it is assumed that modest energy efficiency improvements will be completed in buildings that would undergo renovation in any case for other reasons.

- Rapid development (RD) assumes that the share of low energy buildings will increase rather quickly so that by 2015 most new detached houses are low energy houses. Other construction will follow the development rather quickly, so that low energy buildings will become the norm by 2020. Passive buildings will follow suit and be the norm in new buildings by the 2030's. Moreover, it is assumed that thorough energy efficiency retrofits will be completed in buildings that would undergo renovation in any case for other reasons.

The scenarios use the Rogers (1962) model for the diffusion of innovations for modelling the increase of low energy buildings in new construction, namely that their share in the newly built stock should increase in the form of S-curves. The values were chosen so that the results are in agreement with the current situation and with assumptions explained below. Resulting developments in the future building stock are shown in Appendix B.

In both scenarios the annual amount of energy efficiency improvements completed in renovations is assumed to remain the same, namely 3.5% each year in the building stock built before 2008. This rate is chosen because it agrees with the observed number of renovations in relevant parts of the buildings (Vainio et al. 2002) and because at that rate all of the building stock will be renovated once by 2040–2050. Given that the shell should usually be renovated every 25 to 35 years and plumbing every 50 years (Virtanen et al. 2005), the assumed rate of renovations seems very reasonable, even conservative. The decision was made to only assume energy efficiency improvements in buildings that are renovated in any case because it is doubtful that dedicated energy efficiency retrofits would be cost-effective on their own in most cases.

Table 2. Estimated coefficients for energy consumption achieved with energy efficiency retrofits of buildings (Tuomaala 2008).

	No improvement	**Modest improvement (DD)**	**Significant improvement (RD)**
Shell	1	0.66	0.53
HVAC	1	0.9	0.5

The differences in the scenarios concerning energy efficiency retrofits come from the quality of the improvements, shown in Table 2. The total improvement in energy efficiency is calculated by taking the improved part's share in total heat energy consumption into account. Calculating more parts individually, such as doors or windows, would do little to improve the accuracy since the frequency of their renovations and the improvements they offer are of the same magnitude as are the improvements of the building shell in general (Vainio et al. 2002, Tuomaala 2008). Therefore they can safely be grouped together with the building shell for the purposes of this study.

Of course, the results of this method should not be interpreted in such a way that all renovations result in the same improvements but rather the coefficients in Table 2 should be considered averages. Moreover, the assumptions seem perhaps more realistic if part of the difference in the average improvement is actually interpreted as a slightly lower rate of renovations for DD.

The modelling of the heating energy consumption in buildings was done with MS Excel spreadsheets. It was based on the forecast of the development of the Finnish building stock in the coming decades, estimates of typical energy consumption for different kinds of buildings and the rate of renovations explained above. Using this method, the scenarios for future development were created. The data concerning the building stock was obtained from the EkoREM model developed at the Tampere University of Technology and VTT in 2003–2005 (Heljo et al. 2005).

Table 3. The forecast development of the Finnish building stock in 1000 m^2 (Nuutila 2008).

	Building stock			**Reduction**		**Construction**	
	2007	2020	2050	2007–2020	2020–2050	2007–2020	2020–2050
Detached houses	142 000	163 800	180 200	8 100	44 800	29 900	61 200
Residential buildings	116 200	128 700	131 000	3 800	29 300	16 300	31 600
Commercial buildings	101 800	112 100	119 400	17 700	46 400	28 000	53 700
Total	360 000	404 600	430 600	29 600	120 500	74 200	146 500

For purposes of simplification, the data on the building stock was compiled to three categories: detached houses, residential buildings, and commercial buildings. Detached houses are understood as one-family residences. Residential buildings include buildings that have more than one apartment, namely multistory buildings and row houses. Commercial buildings include buildings in commercial use (offices, stores etc.) and public buildings (schools, hospitals etc.). The choice of categories was made based on the roughly similar typical heating energy use in the buildings grouped together. According to a forecast made with updated data in 14.10.2007, the Finnish building stock will develop as is shown in Table 3 (Nuutila 2008).

The buildings were further categorized according to their age. Again, the age data was acquired from the results of the EkoREM model (Heljo et al. 2005). Then the reduction of old building stock, shown in Table 3, was assumed to consist mostly of the oldest buildings in the stock. Thus the share of buildings built before 1960 would fall at a faster rate than the share of those built during the 1960's, which in turn would outpace those built in 1970's and so on, as is shown in Figure 15. Development along these lines seems reasonable to assume and is deemed to be a satisfactory approximation for the purposes of this study.

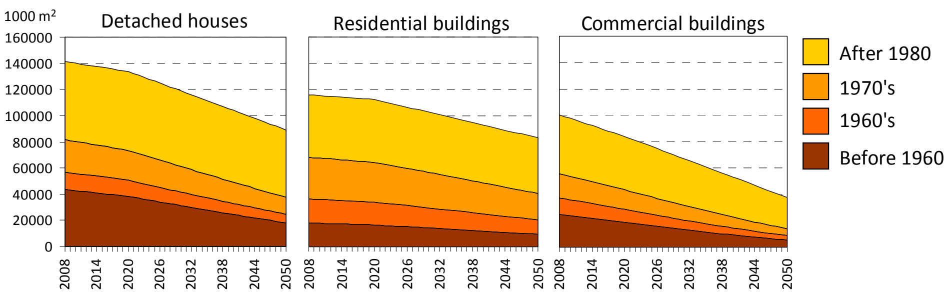


Figure 15. The anticipated reduction in the stock of old buildings, not showing new buildings after 2008, arranged according to construction year.

For each age group of buildings an average consumption of heating energy per m^2 is used to calculate the total consumption. P. Tuomaala (2007) has given the estimates on heating energy consumption according to the age of the building shown in Table 4. The table also shows what consumption figures were chosen for the actual calculations. The choices were made so that the resulting figures would agree with the calculated total consumption of heating energy in each category and age group of buildings as it has been reported by Heljo et al. (2005).

Table 4. Values for annual heating energy consumption in kWh/m^2 sorted by construction year.

	–1960	1960's	1970's	1980–
Estimate according to P. Tuomaala (2007)	160–180	160–200	120–160	100–140
Estimate chosen for residential buildings	180	200	170	120
Estimate chosen for commercial buildings	260	280	250	200

It can be seen that in most cases the choice had to be in and even above the upper limit of the estimate reported by Tuomaala. Also, according to consumption figures from Heljo et al. (2005), energy consumption per m^2 is much higher in commercial buildings. This is to be expected as commercial buildings usually have less insulation and more ventilation than residential buildings.

As a result, the 2008 stock of houses is estimated to consume 22 TWh of heating energy annually, residential buildings 18 TWh, and commercial buildings 24 TWh. The combined estimated annual heating energy consumption is therefore 64 TWh, which is reasonably close to the 66 TWh and 69 TWh estimates given by Heljo et al. (2005) for years 2000 and 2010 respectively.

The future of heating energy use is predicted in a similar fashion. The figures for energy consumption in new buildings, shown in Table 5, are used together with the data from Table 3 to form scenarios of future energy consumption. For passive houses a figure of 20 kWh/m^2 is chosen as it is near the average from the available range of numbers.

Table 5. Values for annual heating energy consumption in kWh/m^2 sorted by building type.

	Norm 2003	Norm 2010	Low energy	Passive
Detached houses	100	70	50	20
Residential buildings	100	70	50	15
Commercial buildings	75	52.5	37.5	9

The energy consumption of the norm building of 2003 is given in accordance with the classification scheme RIL 216-2001 of the Finnish Association of Civil Engineers (RIL 2001). The norm building of 2010 is anticipated to have an energy consumption 30% lower.

Combining the effects of energy efficiency retrofits and efficiency improvements in new buildings for DD and RD scenarios and comparing the results with BAU gives estimates of the overall energy saving potential given two different sets of assumptions. The results for each individual conservation measure assumed here and for all of the scenarios are given in Appendix B.

A final note should be made about the sources of heating energy. Figure 16 shows the anticipated development of heating energy usage in the three scenarios. For old buildings actual data of the heating sources was used. For new buildings, it was assumed that the share for each source of heat will remain the same as it is buildings that have been completed in the past few years.

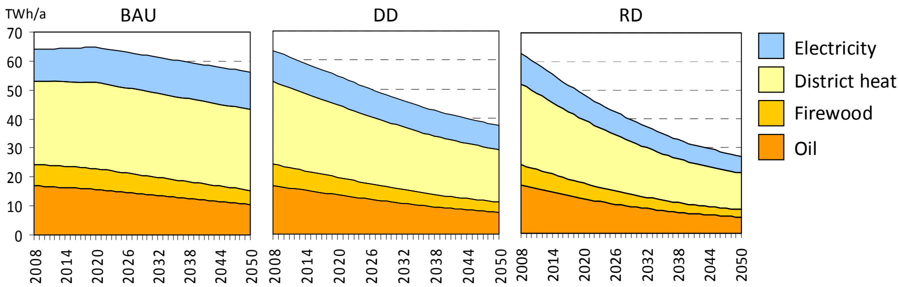


Figure 16. Heating energy consumption for the different sources of heat in the three scenarios.

This is in agreement with the forecasts made in the EkoREM study, although EkoREM anticipates a possible slight rise in the share of district heat coupled with a decrease of electric heating (Heljo et al. 2005). However, low energy buildings would make large investments in heating, such as the instalment of district heating, less attractive – hence the assumption made here of no change in the relative shares is well founded.

Appendix B and Figure 16 show that the modernisation of the building stock is in itself enough to turn the consumption of heat downwards in the long run, even without any particular conservation measures. In the short run energy consumption can be expected to continue to rise if no changes are made in the current practices. On the other hand, investments in new low energy buildings and energy efficiency renovations clearly have the potential to make drastic changes in heating energy consumption even in relatively short periods of time.

By 2020 the measures implemented in the delayed development scenario will allow cost-effective annual energy savings of 7 TWh, which represents more than a 10% drop compared to BAU. By 2050 savings of about 40% are projected. With rapid development the pace of progress nearly doubles: about 25% by 2020 and over 50% by 2050. Such momentous savings would have a measurable effect on the total primary energy consumption in Finland, reaching double digit percentages in the case of the highest estimates.

6. Communities

6.1 Sectoral properties

Communities are defined here as living communities of people, whose physical structure consists of buildings and infrastructure including green areas. Communities are often demarcated as functional aggregates such as commuting areas. Urban form is defined as the way the physical or functional parts are related with each others.

Energy use in communities (city regions, cities, towns, and other urban areas as well as rural communities) takes place in both buildings and infrastructure, during construction, use, maintenance, repair, renovation, demolition, and recycling as well as during transportation of people and goods. That is why energy efficiency of communities must be a composition of energy used during the life-cycle of several physical elements brought together for the community.

Improving energy efficiency means decreasing energy use needed in production of products and services in energy production, transfer, distribution, and use. Energy efficiency in production means producing the same amount of energy with less inputs or producing more energy with same inputs. Energy efficiency in energy transfer and distribution means decreasing energy losses and specific energy consumption in transfer and distribution operations. Energy efficiency in energy use means decrease of specific energy consumption (when other factors are constant). Improving energy efficiency leads to energy saving.

Energy use of communities and urban form consists of production and operation of physical structures and transportation needed by the functions of communities. Impacts of urban development on energy efficiency often turn up in connection of impacts on other sectors.

Changes in urban and regional forms affect energy consumption and greenhouse gas emissions directly via amount and location of structures, i.e. buildings, networks and other structures, and transportation between functions, and in the other hand via other changes, e.g. changes linked with living standard, motorizing, and amount of transport as well as their combined and multiplex effects. Multiplex and circuit effects appear for example in modal split where motorizing increases share of cars, which promotes urban sprawl, which again promotes the use of cars. (Harmaajärvi et al. 2001, 2002, Harmaajärvi et al. 2004)

Share of energy use for the built environment was 59% of end use of energy and 56% of greenhouse gas emissions in Finland in 2007. Built environment consists of buildings (38% of energy end use, 32% of greenhouse gas emissions), construction of buildings and infrastructure and production of building materials (4% of end energy use, 6% of greenhouse gas emissions), and fuel and electricity consumption for transportation (17% of energy end use, 19% of greenhouse gas emissions) (Martinkauppi (ed.) 2010).

Urban form or built environment is a significant part of national economy, about 35–45% of GNP and 75% of national capital in Finland (Heinonen et al. 2002).

Built-up areas in Finland typically use much more land per inhabitant than built-up areas in other western countries, or even in the other Nordic countries. Finland's regional and urban forms have for long been characterized by the development where the regional form is becoming more concentrated, while urban sprawl is causing fragmentation of the urban form. (Harmaajärvi et al. 2001, 2002). This means longer commuting and business distances, high infrastructure and transportation costs, waste of natural resources and areas as well as greenhouse gas emissions. Integration of urban form is one of the main targets in the national land use targets and long term climate and energy strategy.

Planning solutions may, according to the results of case studies, impact on primary energy consumption and greenhouse gas emissions by 10% at regional level, by 60% at local community level, and even by 200% at local dwelling area level. Impact on emissions caused by transportation is even bigger: at least double compared to the impact on total emissions. Similarly large impacts can be seen concerning consumption of energy and other natural resources as well as costs. (Wahlgren 2009)

The most important factors in sustainable urban planning are at dwelling area level: location, structure, building density, house types, space heating systems, at community and regional level: area density, energy consumption and production systems, location of and distances between dwellings, working places, and services, transportation systems, possibilities of walking and cycling, availability of public transport, and necessity for use of private cars (Wahlgren 2009).

Urban form and greenhouse gas emissions at the national level were studied when preparing the National Climate Programme of Finland in 2000. The study showed that it is possible to reduce greenhouse gas emissions by 2.3 million tonnes in 2010 by developing the urban form in a target-oriented way. This amounts to 15% of Finland's target in accordance with the Kyoto protocol for greenhouse gas emissions reductions (Harmaajärvi et al. 2001, 2002).

According to a recent study about urban land use patterns and greenhouse gas emissions in Finland 2005–2050 (Lahti & Moilanen 2010) dense and centralised urban form can strengthen effectiveness of climate change mitigation actions and prevent losing good results of other actions. Continuing urban sprawl may weaken impacts of other actions by 30% and a dense structure may strengthen them by even 20%.

The energy efficiency committee of Ministry of Employment and the Economy assessed that energy saving potential of land use and transportation planning would be totally 540 GWh in 2020 (Ministry of Employment and the Economy 2009).

System boundaries for measuring energy efficiency of communities can be defined by different areal, administrative, or planning levels, or by functional basis. Measuring energy efficiency of communities is based on characteristics of urban form and consists of several factors: buildings, networks and other structures (infrastructure), and transportation between functions. Possible system boundaries for communities are presented in Figure 17.

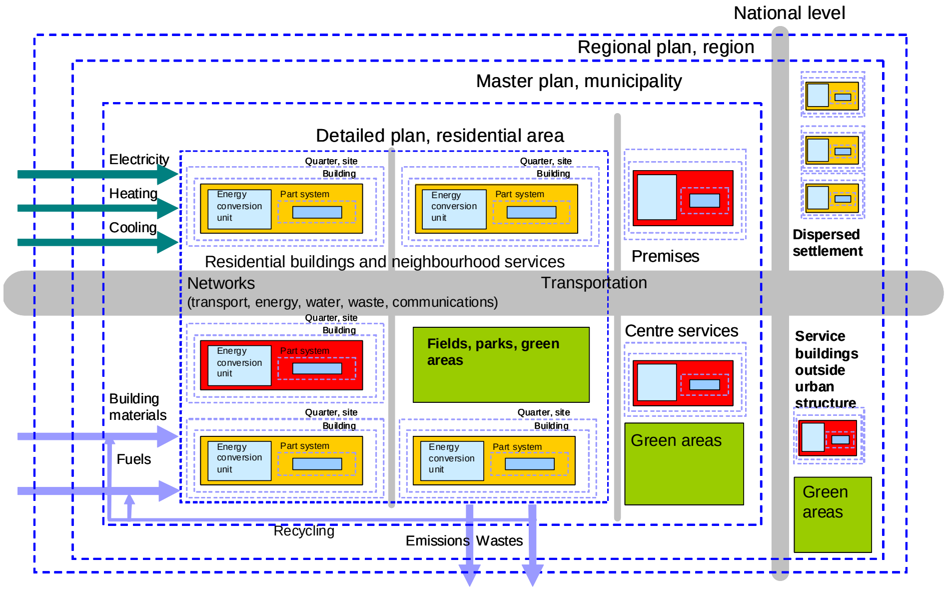


Figure 17. System boundaries for measuring energy efficiency of communities.

The most limited system boundary concerns residential or other neighbouring area planned by detailed plan. This boundary includes the following factors:

- residential buildings
- premises (neighbouring premises)
- fields, parks, green and leisure areas (neighbouring areas)
- networks (infrastructure): transportation, energy, water, waste management, communications
- transportation (from functions of the area).

System boundary for master plan level, area of a municipality, part of it or several municipalities, includes the following factors:

- factors of detailed plan level
- city centre services
- other premises (wide area)
- green and leisure areas (wide, serving the whole community)
- connection networks
- transportation (from functions of areas and inside community).

Regional level system boundaries include the following factors:

- factors of detailed and master plan levels
- scattered settlement
- services outside communities
- wide forests and green and leisure areas
- regional and nationwide networks
- transportation (from communities and inside regions).

System boundaries by functional basis could be defined for example:

- immediate surroundings: dwelling, neighbouring services (day-care centre, school, shop, park, recreational area, bus stops), or daily environment
- community: wider area, or weekly environment
- commuting area: dwellings, work places, centre services, recreational areas, may include several communities.

6.2 Defining indicators

Energy efficiency of communities can be defined as a ratio between an input of energy consumption or emissions, and an output of services, such as number of inhabitants and workplaces or floor square metres.

Energy efficiency of communities measures efficiency of energy use in production (construction) and operation of communities. Efficiency of energy use describes consumed energy in relation with gained benefits. Benefits are wideness, capacity or serving capability of communities. Indicators describing them are usually the total floor space or volume of buildings, sometimes also number of inhabitants or work places. Production of communities includes the whole production process of building materials needed in buildings, infrastructure and construction. Operation of communities include use and maintenance of buildings and other structures (space heating, cooling, other use of electricity, maintenance etc.) as well as personal and goods transportation needed by functions of communities (commuting, business, leisure trips and transports).

Important points of view are for example primary energy demand, production of greenhouse gas emissions and use of renewable and non-renewable energy sources. Life-cycle viewpoint is essential for energy efficiency measurement.

6.3 Indicators of energy efficiency

Energy efficiency of communities can be defined as the amount of nonrenewable energy sources used in communities (production, operation and transportation) in relation to amounts of units which describe the wideness or service capability (such as floor space or volume of buildings, number of inhabitants and workplaces).

A compact definition could be:

> Energy efficiency of a community or an urban form can be considered in two ways (inverse with each other):
>
> (1) "Energy efficiency of an urban form is (non-renewable) energy use and emissions relative to services produced by the community, such as the number of inhabitants and workplaces or floor square metres."
>
> OR
>
> (2) "Energy efficiency of an urban form is services, products and other quality of life produced by a community relative to (non-renewable) energy sources and produced emissions by their production, operation and transportation."

Definition (1) can be seen as the principal and traditional indicator of energy efficiency. According to it energy efficiency increases when this ratio decreases. Concrete indicators can be these ratios:

- kWh, MJ/floor-m^2
- kWh, MJ/inhabitant
- kWh, MJ/workplace
- CO_2-eq. t/floor-m^2
- CO_2-eq. t/inhabitant (inh)
- CO_2-eq. t/workplace (wp).

Use of floor-m^2 in comparison with dwelling-m^2 or useful-m^2 or building volume m^3 can be justified for many reasons:

- floor-m^2 is one of the most important tools in urban planning
- building right (permitted building volume) is defined as floor-m^2
- floor-m^2 describes the concrete physical structure more accurately than the others (indoor space available to furnish and move measured as floor area)

- developers and constructors know the concept (also dwelling- m^2 and useful-m^2)
- dwelling-m^2 and useful-m^2 measure better the space that actually is produced (physical indoor space), but lead to unwanted minimization of side spaces (starecases etc.)
- building-m^3 describes best heated and cooled indoor space
- all quantities which measure indoor space leave outdoor structures (balconies, porches, sheds etc. yard buildings) outside measuring.

The following efficiency indicators can be used alternatively or in parallel depending on the focus of the assessment:

- Energy consumption per total (useful) floor space in the community (kWh/floor-m^2_{useful})
- Energy consumption per inhabitant and workplace in the community (kWh/inhabitants+workplaces)
- Non-renewable energy consumption per total (useful) floor space in the community (kWh/floor-m^2_{useful})
- Non-renewable energy consumption per inhabitant and workplace in the community (kWh/inhabitants+workplaces)
- GHG emissions (carbon footprint) per total (useful) floor space in the community (CO_2-eq. tons/floor-m^2_{useful})
- GHG emissions (carbon footprint) per inhabitant and workplace in the community (CO_2-eq. tons/inhabitants+workplaces).

In addition to these also more sophisticated qualitative factors (like aesthetics of urban design, architecture, air quality etc.) can be taken into account (if the floor space or the amount of inhabitants and workplaces are not considered to represent the social and individual benefits gained by the use of energy in a sufficient way), but they need a separate assessment procedure.

Mathematical formulas for energy efficiency of communities may be described in several alternative ways. Energy efficiency of communities (buildings, infrastructure, transportation) presented per time unit (one year):

$$EEnC_{inhwp} = \frac{kWh_{production} + kWh_{operation} + kWh_{transportation}}{(inh + wp), a} \quad (6.1)$$

$$EEnC_{floor\text{-}m2} = \frac{kWh_{production} + kWh_{operation} + kWh_{transportation}}{floor\text{-}m^2, a} \quad (6.2)$$

$$EEmC_{inhwp} = \frac{CO_2\text{-eq.t}_{production} + CO_2\text{-eq.t}_{operation} + CO_2\text{-eq.t}_{transportation}}{(inh + wp), a} \quad (6.3)$$

$$EEmC_{floor\text{-}m2} = \frac{CO_2\text{-eq.t}_{production} + CO_2\text{-eq.t}_{operation} + CO_2\text{-eq.t}_{transportation}}{floor\text{-}m^2, a} \quad (6.4)$$

Energy efficiency of communities from a wide view (per time unit one year):

$$EEnEmC = \frac{\text{Services, products, quality of life}}{kWh,\ CO_2\text{-eq.t, a}} \quad (6.5, 6.6)$$

Energy efficiency of communities (buildings, infrastructure, transportation) presented over the whole life cycle (for example 50 years):

$$EEnC_{inhwp} = \frac{kWh_{production} + kWh_{operation} + kWh_{transportation}}{inh + wp} \quad (6.7)$$

$$EEnC_{floor\text{-}m2} = \frac{kWh_{production} + kWh_{operation} + kWh_{transportation}}{floor\text{-}m^2} \quad (6.8)$$

$$EEmC_{inhwp} = \frac{CO_2\text{-eq.t}_{production} + CO_2\text{-eq.t}_{operation} + CO_2\text{-eq.t}_{transportation}}{inh + wp} \quad (6.9)$$

$$EEmC_{floor\text{-}m2} = \frac{CO_2\text{-eq.t}_{production} + CO_2\text{-eq.t}_{operation} + CO_2\text{-eq.t}_{transportation}}{floor\text{-}m^2} \quad (6.10)$$

Energy efficiency of communities from a wide view (over the whole life cycle, for example 50 years):

$$EEnEmC = \frac{\text{Services, products, quality of life}}{kWh,\ CO_2\text{-eq.t}} \quad (6.11, 6.12)$$

There are several energy efficiency indicators which consist of different parts and phases. Indicators complete each other.

6.4 Intersectoral interfaces

Measuring energy efficiency of communities is strictly connected to other sectors.

- Buildings are part of an urban form or built environment and their results on energy efficiency are directly included in measuring energy efficiency of communities. Energy efficiency of buildings is connected to energy efficiency of communities both by energy used in operation phase and energy embodied in building materials.
- Energy efficiency of energy production chain is also connected directly to measuring energy efficiency of communities. This concerns both energy consumption of buildings and infrastructure and areal energy systems such as district heating and electricity networks.
- Interfaces of energy efficiency of industry and communities concern e.g. production efficiency of building materials and fuels.
- Interfaces of energy efficiency of logistics and communities concern also efficiency of logistics of production of building materials and fuels. There are significant interfaces also concerning waste logistics and transportation of communities.

Figure 18 describes the factors of energy efficiency of communities and their connections to other sectors of the EPO project.

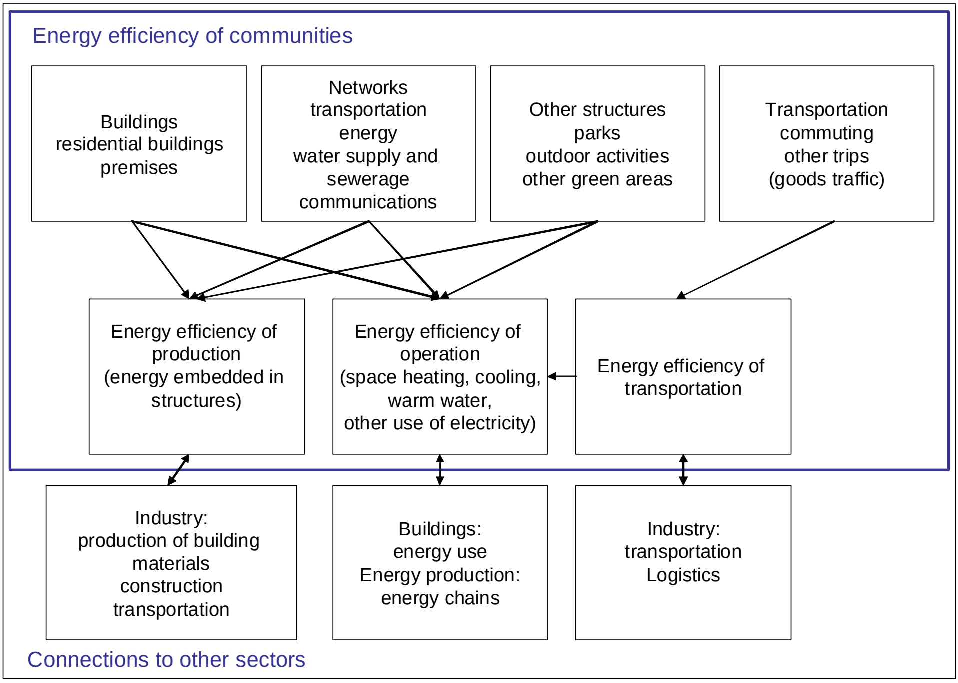


Figure 18. Energy efficiency of communities and connections to other sectors.

6.5 Indicators and life cycle of communities

When measuring energy efficiency of communities an essential point of view is to consider the whole life cycle of all the structures and transportation. Life cycle of communities consists of production of structures or energy embedded in the materials of the structures (buildings, networks and other structures), operation of structures, and transportation needed by the functions of the communities.

Figures 19–21 describe life cycle point of view in different components of communities: buildings, infrastructure, and transportation.

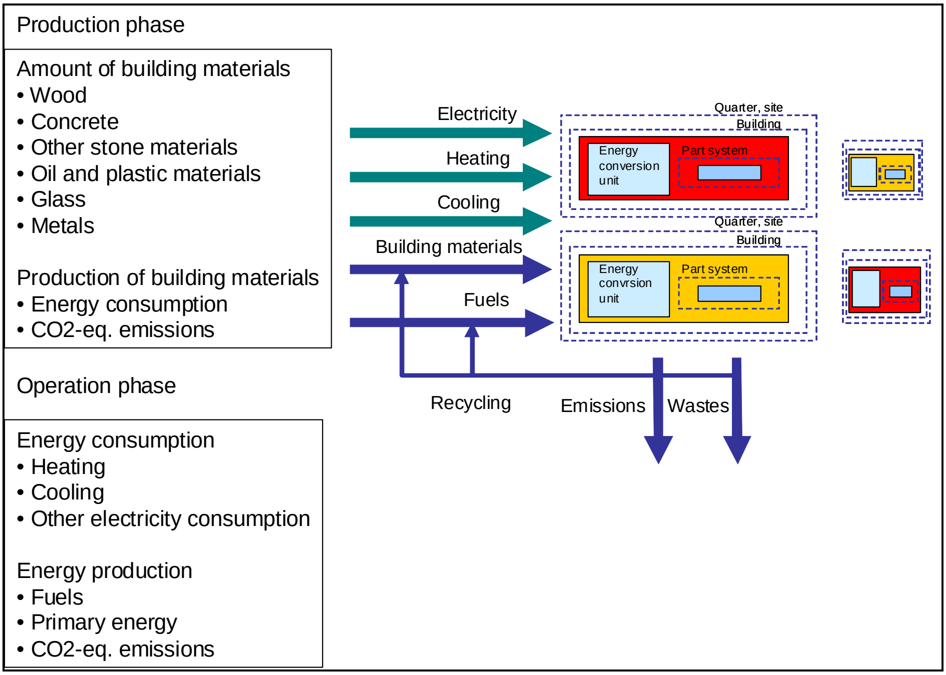


Figure 19. Energy efficiency of communities - life cycle assessment of buildings.

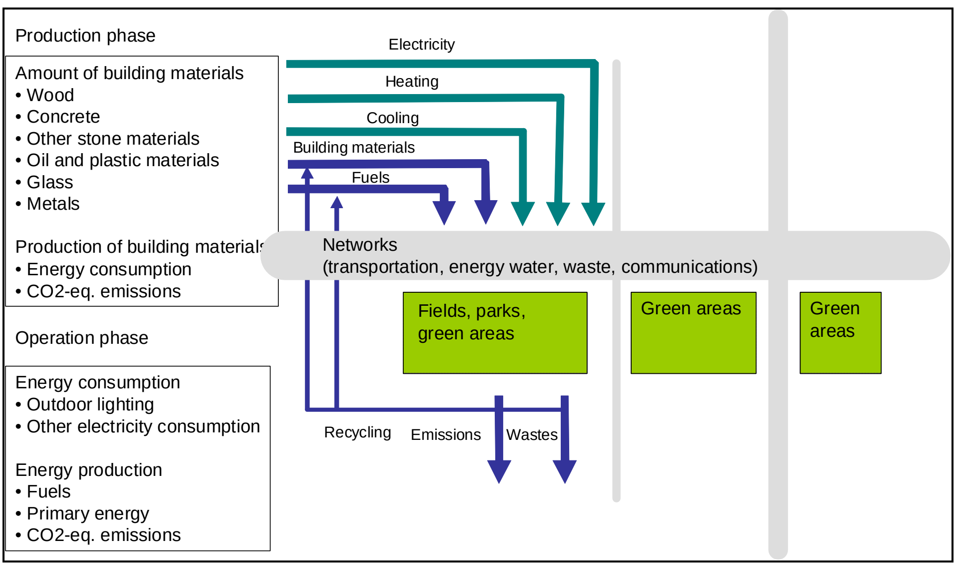


Figure 20. Energy efficiency of communities – life cycle assessment of infrastructure.

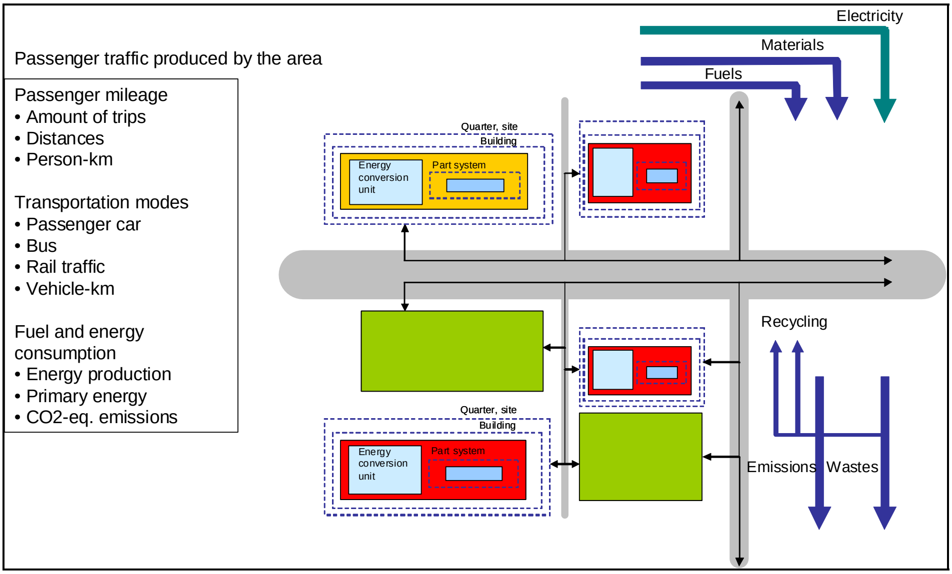


Figure 21. Energy efficiency of communities – life cycle assessment of transportation.

Case studies about energy efficiency of communities show that production phase forms less than 10% of the total energy consumption. Operation phase forms most of the energy consumption. Depending on location and traffic-related circumstances, transportation may have a very important role in total energy consumption of a community, and transportation causes greatest differences between areas.

Figures 22 and 23 present examples of the share of energy consumption during different phases of structures and transportation. Figure 22 describes the annual energy consumption and Figure 23 the cumulative energy consumption of different phases and factors of a residential area.

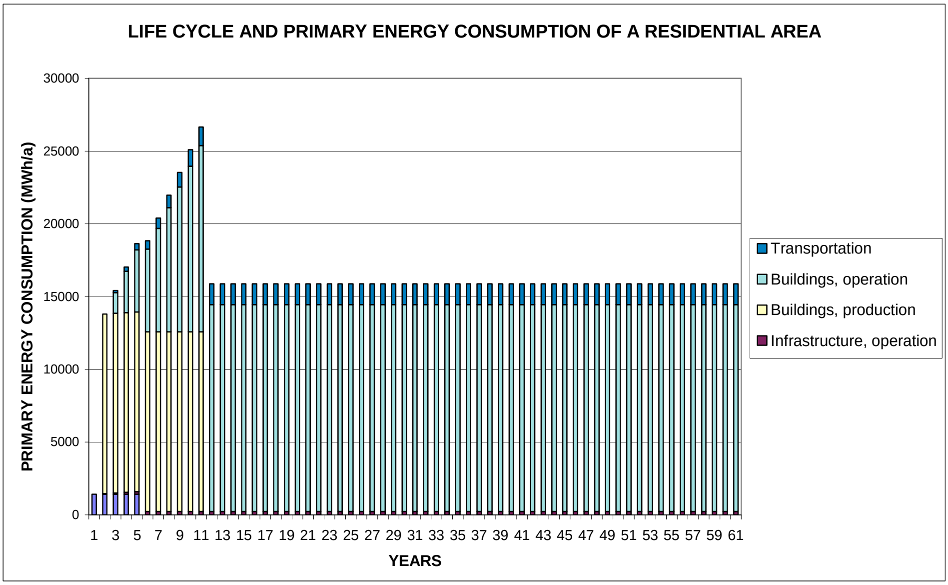


Figure 22. An example of annual energy consumption of a residential area.

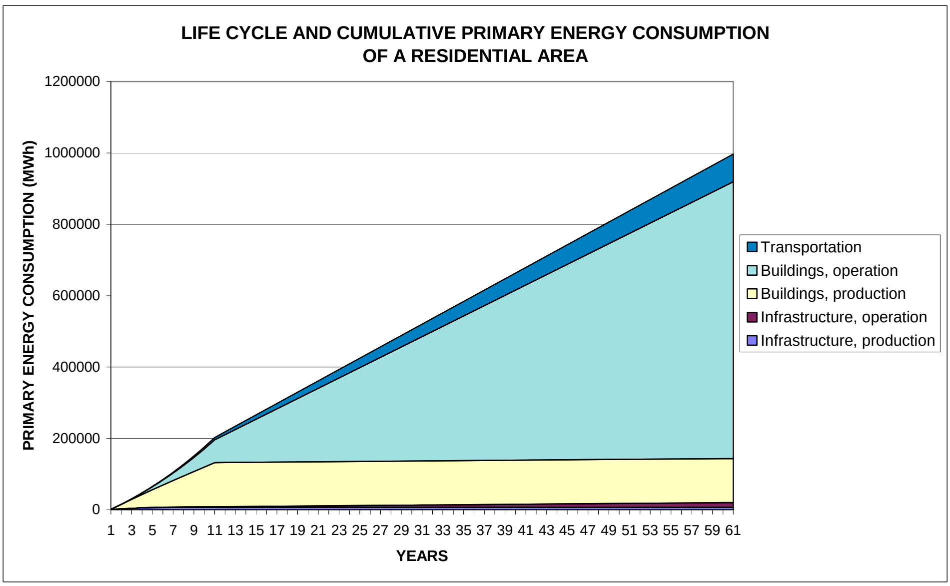


Figure 23. An example of cumulative development of energy consumption of a residential area.

Utilization rate in measuring energy efficiency of communities is important concerning buildings, and it has the same features as described in the building sector part of the report. Utilization rate of infrastructure is important, as in many cases networks are built before buildings, and a remarkable part of buildings may be not executed at all. Integrating, infill, and compacting of urban form promote increasing the utilization rate of infrastructure and thus improving energy efficiency.

6.6 Examples of potential evaluation

6.6.1 Factors affecting energy efficiency of communities

Communities may have a relatively high potential for energy efficiency improvements. Potential seems to be highest in the operation phase of structures and in transportation. Measuring energy efficiency and potentials of communities are connected strictly to other sectors of the research: buildings, energy production, industry, and logistics.

Energy efficiency of communities can be affected by choices in developing urban form meaning the ways buildings and infrastructure have been combined. Infrastructure includes transportation, energy, water, waste management, and communications networks with facilities. Basic characters of urban form are e.g. area density, population density, block structure and network density, unit size and location choices, public transportation systems, technical service network structures, block shapes, real estate, and site layout, building types, issues regulated by detailed, and other plans and instructions for construction methods, such as location of buildings on site, eaves heights, types of roof etc. Many of these directional means may have a significant impact on energy efficiency of a community.

Most favourable urban form models as for energy efficiency are based on walking, bicycling and effective mass transport, especially railway transport, and location of housing in urban areas and villages, relatively dense building, whereas in less favourable models housing is emphasized in loosely structured and dispersed settlement and transportation is based on use of private cars.

Factors effecting energy efficiency of communities are e.g.:

- Location, distances
- Urban sprawl – integration to urban form

- Building density (area density, site density) floor-m^2/land-m^2
- Structure of networks (transportation, water supply and sewerage, energy, communications)
- Wideness of networks m/floor-m^2, m^2/floor-m^2
- Living space floor-m^2/inhabitant, working place space floor-m^2/work place
- House types
- Utilization of micro climate, passive solar energy
- Space heating systems (incl. utilization of district heating possibilities)
- Energy production systems (incl. local energy sources)
- Facilities
- Consumption habits
- Transportation system
- Modes of transport, choices
  - Prerequisites for walking, bicycling and public transport.

6.6.2 An experimental calculation of energy efficiency potentials of communities

Experimental calculations were made for the basis of a calculation model for energy efficiency of communities. Energy efficiency and energy saving potential of residential area ("neighbouring environment", detailed plan level) were estimated as follows (connections to other sectors are in brackets):

1. Energy embodied in buildings
   - Materials in buildings (Buildings)
   - Potential of building material production (Industry, Energy, Logistics)
2. Energy consumption of buildings during operation phase
   - Potential of space heating energy (Buildings, Energy)
   - Potential of electricity use (Buildings, Energy)
   - Potential of warm water (Buildings)
3. Energy embodied in infrastructure
   - Structure of the area – amount of networks – amount of materials

- Potential of building material production (Industry, Energy, Logistics)

4. Energy consumption of infrastructure during operation phase
   - Outdoor lighting (Energy)
   - Transfer losses (may be included in buildings or in primary energy calculations) (Energy)
   - Energy use in systems

5. Energy consumption of transportation (Transportation).

Following presumptions were used in calculating energy efficiency potentials of a residential area:

1. Energy embodied in buildings
   - Energy saving potential of materials production on average 20%

2. Energy embodied in infrastructure
   - Decreasing potential of amount of networks 50%, energy saving potential of materials production on average 20%

3. Energy consumption of buildings during operation phase
   - Energy saving potential on average 60%

4. Energy consumption of infrastructure during operation phase
   - Energy saving potential on average 60%

5. Primary energy consumption of transportation
   - Decreasing potential of transportation need 50%, energy saving potential of modal split + vehicle technology 50%.

These presumptions are based on government targets for the year 2050. Gaining the target of material production energy may require for example limitations in energy intensive materials use and increasing of carbon sinks (wooden and wood based materials) when net carbon footprint decreases.

Figures 24 and 25 present results of potential calculations. According to the results it is possible to improve energy efficiency (decrease energy consumption) of a residential area over the whole life cycle total nearly 60%. The greatest potentials are in operation phase of buildings and in transportation.

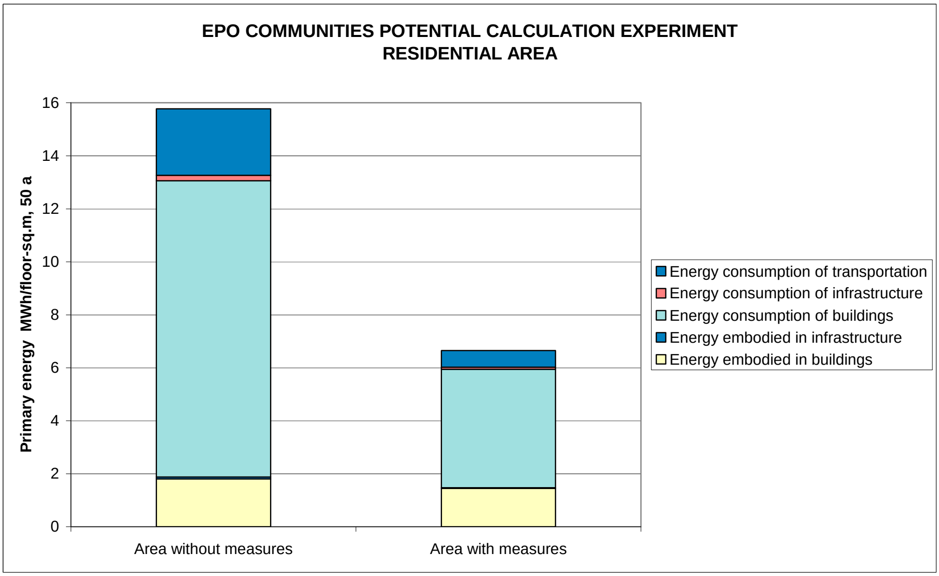


Figure 24. Experimental potential calculation on residential area level. Energy efficiency and energy saving potential of an area.

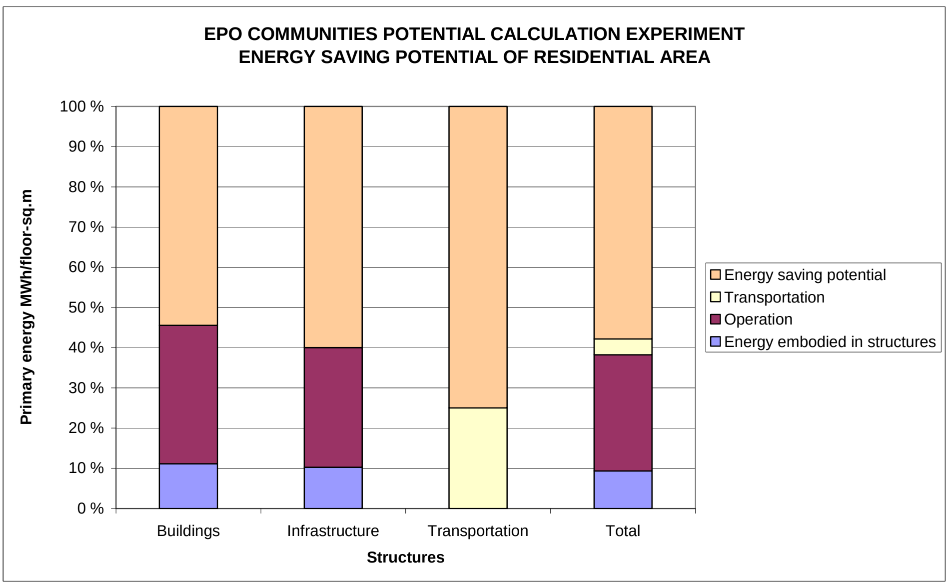


Figure 25. Experimental potential calculation on residential area level. Relative energy saving potential of an area concerning different structures and transportation and the whole complex.

7. Energy system

Finnish national energy system is quite diversified. Also, Finnish energy system is fairly decentralised with geographic characteristics in energy production: gas pipeline reaches southern parts of Finland, coal power plants are mainly situated on the coastal area, main wood fuel and peat resources are in Central, Eastern, and Northern Finland.

End use of energy is characterised by two main consumers: energy-intensive industry (49% share in 2005) and space heating (21%). Pulp and paper production is the main industrial energy consumer, especially using electricity and process heat, followed by iron and steel industry and chemical industry. However, byproducts from pulp and paper industry constitute a major part of Finnish renewable energy sources.

Electricity and heat production sector consists mainly of nuclear power, hydro power, quite diverse thermal power production using natural gas, coal, peat fuel, and biomass. Consumption of district heating guides CHP production with 72% of district heat produced by CHP in 2005 and a vast autoproduction capacity supplies process heat and electricity to industrial sector.

Finland is a member of Nord Pool power exchange with Sweden, Norway, and Denmark, and electricity is thus produced, imported and exported depending on Nordic electricity market prices. Therefore, e.g. conditions on Norwegian hydro power production affect Finnish condensing power production. Main import source of electricity outside of Nord Pool is Russia with 35 PJ in 2005. Since emission trading has increased production cost of coal and peat fuel based power, investments in condensing power, excluding nuclear power, are decreasing with the share of CHP increasing due to its high efficiency and growing popularity of district heating.

7.1 Sectoral properties

The energy system can be described as a series of supply chains starting from extraction of resources and, through a number of conversion, transportation, and distribution processes, finishing to the end use of energy either as heat, power, steam, or an arbitrary combination of these in order to satisfy a specific need. These energy chains are numerous and for almost every raw material there are many alternative routes that can split and join up again while making their way on these production paths towards the end use of energy. The main processes in these energy chains are described in Table 6.

Table 6. A listing of processes in an energy chain, their descriptions with examples.

Process	**Description**	**Examples**
Resource	Choice of the resource or raw material	Oil, coal, wood, wind, sun
Resource extraction	Extraction of the resource for processing	Mining, harvesting, by-product utilization
Transportation of resources	Transportation of the resource	Tankers, shipping, pipelines, road transportation
Conversion	Refining the chosen resource into a more useful energy carrier	Petrochemical refinery, gasification, pelletizing, chipping, drying
Transportation of fuel	Transportation of refined fuel from pre-production conversion to the energy production facilities	Tankers, shipping, pipelines, road transportation
Energy production	Conversion of fuel or pure mechanical energy to a combination of electricity and heat	CHP and condensing power plants, nuclear plants, wind mills,
Distribution	Providing the end use conversion the required quantity of energy in an appropriate form	DHC pipelines, electric power network
End use conversion	Final conversion of energy to satisfy a specific need	Radiator system, heat pumps, appliances, a variety of machines
End use	Energy gained	Heating, cooling, power

Unlike what this somewhat polished listing of processes in the energy chains might suggest, the definition of individual chain is not as straightforward for every energy chain as not all the processes are presented in every alternative and some cases might even come out as a crude network rather than a chain of processes when e.g. heat is recoverable for end use in pre-production extraction or conversion processes. Also, a single process might include several sub-processes, e.g. chipping, drying, and pelletizing of wood in a conversion process. While the presented definition of energy chains does set up an adaptive framework for describing the individual supply chains in energy systems on a general level, it is especially useful for comparing a limited number of cases, e.g. the alternative chains for a given resource. The basic idea of energy chains is, however, behind any energy system model to some extent.

7.2 Defining indicators

When dealing with the measuring of energy efficiency in the energy sector, the coefficient of efficiency is an obvious and a closely associated concept. As stated in the previous Chapter 7.1, the energy system can be understood to contain a number of energy chains which in turn can be divided into processes, each with a perceived flow of material and energy in and out where the material flow can easily be converted into energy using its heating value. As ia well known, the coefficient of efficiency is defined as a ratio of energy out to energy in. When this principle is applied to processes in an energy chain, energy out can be presented by subtracting energy used in the process from energy flowing in to the process.

$$\eta_i = \frac{E_{out}}{E_{in}} = \frac{E_{in} - E_{used}}{E_{in}} \tag{7.1}$$

When defining the coefficient of efficiencies for each of the processes on a selected supply path, the individual efficiencies can be used to calculate a chained coefficient of efficiency describing the efficiency of the energy chain in total as

$$\eta = \prod_{i=p_0}^{p_n} \eta_i \, , \tag{7.2}$$

where *i* is the designation of a process *p* and *n* the total number of processes in the energy chain in question. This overall efficiency can be used to calculate e.g. the remaining energy of a resource after a specific energy chain.

$$E_{end\ use} = \eta E_{resource} \tag{7.3}$$

The definition above can also be used to calculate other useful meters such as primary energy use and by applying process specific coefficients concerning e.g. greenhouse gas emissions, other results such as total emissions in a selected energy chain can be obtained.

7.3 Indicators of energy efficiency

The calculation of the total efficiency of an energy production path, i.e. a chained coefficient of a defined set of processes in an energy chain needs information on parameters for all included processes. As an example, two energy chains describing heat and power production by a CHP plant using either wood chips processed from forestry residue or natural gas as fuel have been defined. The forest residue is gained as a by-product of forestry thus the resource extraction only takes into account the handling of this residue, not the energy cost of actual harvesting. The results with the set of parameters used in calculation are presented in Table 7 and the Figure 26 illustrates the energy chain in question in a graphical form.

The other relevant parameters in the energy chain calculation for wood chip based production are the power to production ratio (power / (power+heat)) and the distance the wood chips are transported, which are 0.50 and 120 km, respectively. Referenced values in process efficiencies are used for wood extraction, refining, and transportation (Mäkinen et al. 2006), electrical and district heating network losses (Energy Industry 2007b). Moisture content of the wood chips is assumed to remain unchanged at 45%. The natural gas based production has a power to production ratio of 1.00 and the natural gas is transported through pipelines from Urengoy gas fields in Russia for 3 300 km and 300 km inside the borders of Finland. The coefficient of efficiency in power production is 0.85 for wood chips and 0.90 for natural gas based production. Other values used are established averages.

Table 7. Process specific efficiencies (η_p) and their cumulative (η_{cum}) effect of energy chains using wood chips or natural gas for CHP production.

	Wood chips			Natural gas		
Process	**Description**	η_p	η_{cum}	**Description**	η_p	η_{cum}
Resource	Wood	-	1.000	Natural gas	-	1.000
Resource extraction	Relocation of forestry equipment	0.997	0.997	Extraction of natural gas	1.000	1.000
Resource transportation	Forest transportation	0.995	0.992	-	-	-
Conversion	Chipping of wood material	0.991	0.983	-	-	-
Transportation of fuel	Transportation of wood chips	0.980	0.963	Pipeline transportation (3 600 km)	0.914	0.914
Energy production	Wood chip based CHP	0.850	0.819	Natural gas based CHP	0.900	0.822
	Electricity	0.283	0.273	Electricity	0.450	0.411
	Heat	0.567	0.546	Heat	0.450	0.411
Energy distribution	Distribution to consumers	0.935	0.766	Distribution to consumers	0.935	0.769
	Electrical network	0.964	0.263	Electrical network	0.964	0.396
	District heating network	0.909	0.496	District heating network	0.909	0.374
End use conversion	Using the distributed energy	0.974	0.746	Using the distributed energy	0.974	0.749
	Home appliance	1.000	0.263	Home appliance	1.000	0.396
	Radiator heating system	0.950	0.471	Radiator heating system	0.950	0.355

When contemplating the values of Table 7, it is obvious that the process specific pre-production efficiencies are quite decent and if compared to the effect of naturally drying the wood, the conversion and transportation processes seem quite insignificant. If by drying the wood from 40 percentage of moisture to 30%, the heating value increases by 20%, the pre-production efficiency of the example being about 4%, the benefit of drying, at least by natural means, is obvious.

What needs to be kept in mind is that an energy efficient process is not necessarily a cost efficient one. While being quite efficient for the energy chain point of view, the pre-production phases of the chain can be quite costly. Likewise the facilities required for additional drying, especially if active drying is used, have a price tag attached.

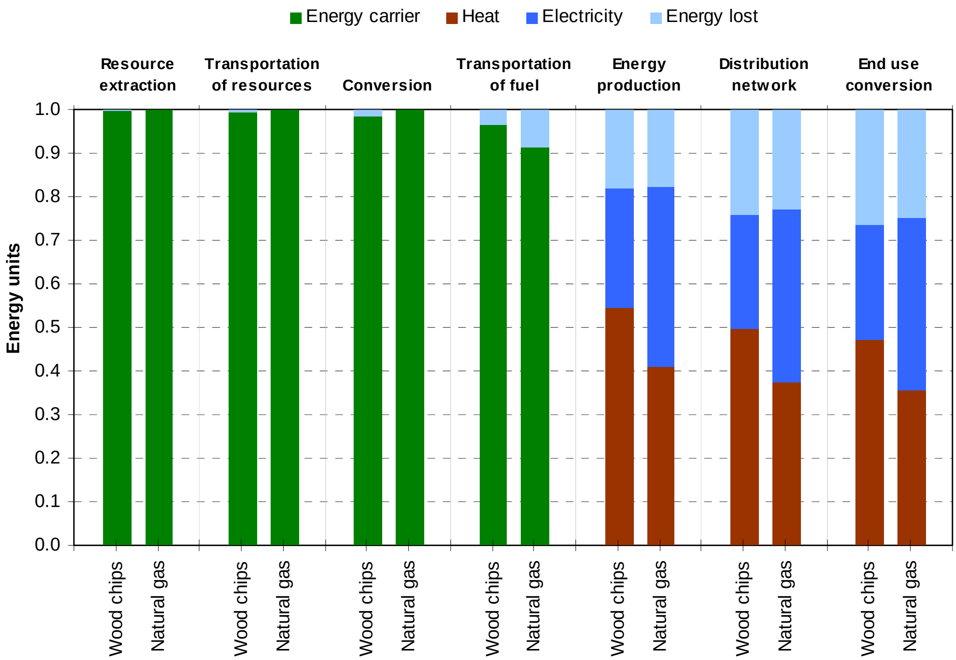


Figure 26. Two examples of an energy chain using wood chips or natural gas for CHP production.

7.4 Sectoral interfaces

The energy system has significant connections to all of the other sectors in various points and parts, but the strongest connection is established by the producer/consumer relation of the energy supply chain. The consumer is defined here as an entity with a need for energy either as electricity, heat or cooling. This connection between a consumer and a producer exists on every level; also beyond the national level and inside the inner production level Boundary A (internal use).

Other than the connections between the energy sector and the residential, industrial, commercial and public consumers, the sector is also connected to communities by location and local regulations (e.g. concerning emissions) and to logistics by the services required, for example fuel transportation.

Figure 27 illustrates these connections within the energy system and beyond by setting up boundaries between the chief levels of the operating environment and defining the flow of energy, information or material through or within them.

Figure 28 illustrates boundary areas inside the energy production. Combination of power plant can be built based on those modules. Each module has input and output with defined parameters. The efficiency can be formulated by input and output. Also input or output can be defined, if we know technical construction of the module and thermodynamic and flow dynamic properties. Typical values for those efficiency values are presented in the Table 7.

The simplified concept for sun, wind, hydro power, heat pump, and fuel cell is presented in Figure 29.

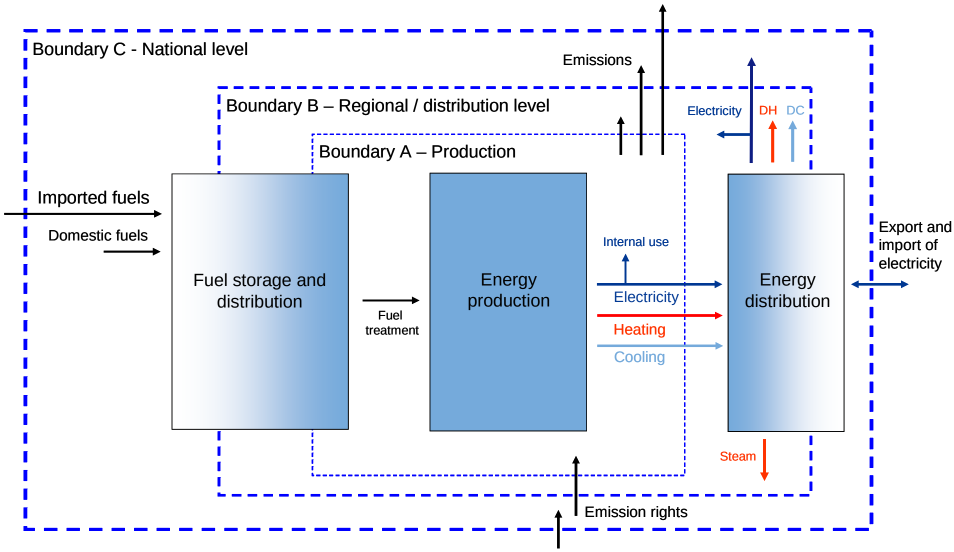


Figure 27. The main components and interactions within the energy sector and the connections to different levels of the operating environment.

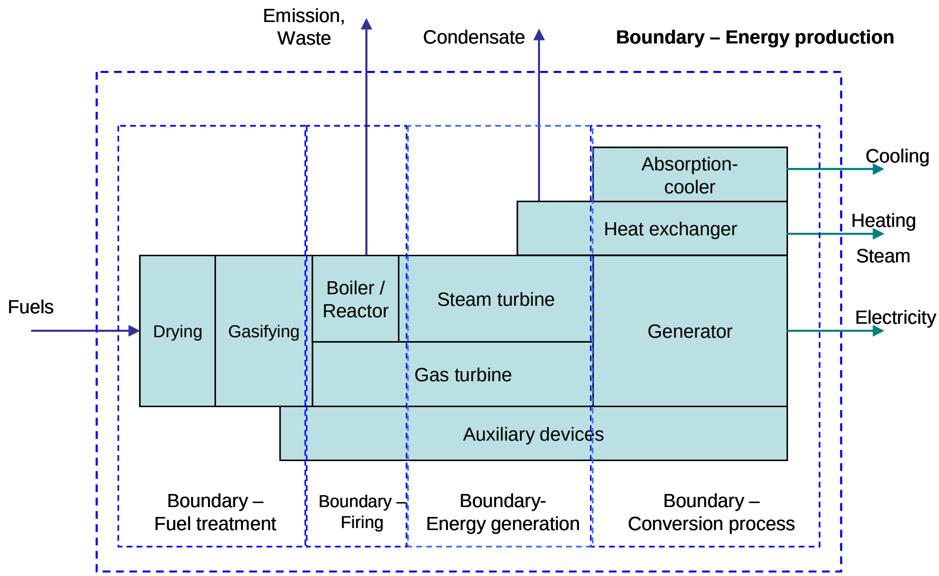
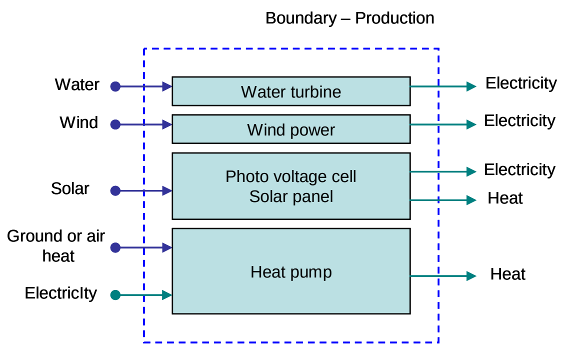


Figure 28. Energy production divided in four energy boundary areas and pieces of main components in each energy boundary.



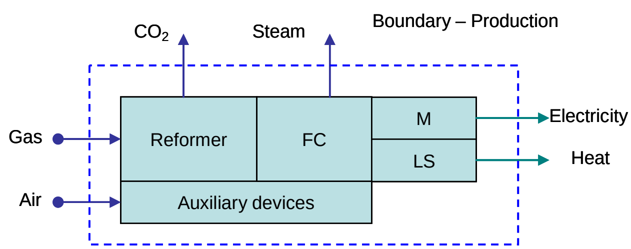


Figure 29. Conversion process of hydro, wind, solar, and fuel cell power as well as heat pump.

7.5 Load curves and partial loading

An example of district heat and power annual demand by hours is shown in Figures 30 and 32 and the corresponding duration curves in Figures 31 and 33. As noticed in figures the demand varies much between four seasons a year – especially in district heating – and even in hours during a day. The outdoor temperature variation causes heat demand load changing, which is 4 to 5 times higher comparing winter load to summer load. Heat load is mainly space heating and hot water demand in winter and hot tap water demand in summer time. The demand variation is not so high in electricity between summer and winter, but hourly variation during a day might be high.

Operating the power plants must be planned carefully so that the best combination of power units is available for producing energy with the best efficiency. That is why different type of power plants must be available. They are basic load, middle load, and peak load power plants for those areas shown in Figures 30, 31, 32, and 33. Basic load power plants are combined heat and power plants, big condensed power plants, or heat only plants. The basic load plants need long annual operating time because of high investment cost, and driving cost is dependent of utilisation time. Peak load units are quick start-up or easy to regulate plants e.g. gas turbine, diesel, or hydro power plants as well as heat only boilers are gas or oil fired.

Figure 34 presents three efficiency types of power plants. The efficiency of the power plant is decreasing in partial load. The efficiency of the turbine plant might be a function of load powered to two or three. Heat only boiler plant is nearly a linear function of load. If a minimum of 70% energy efficiency is wanted, load level of the power plant type1 could be regulated only 10%, type2 and type3 could be regulated 20 and 50%.

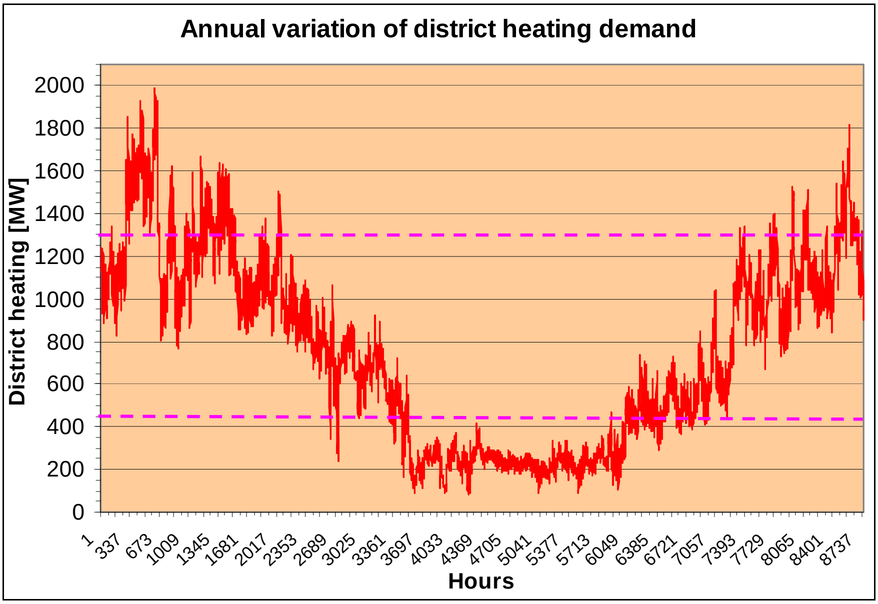


Figure 30. Season and hourly variation of district heat load divided in basic, medium and peak load.

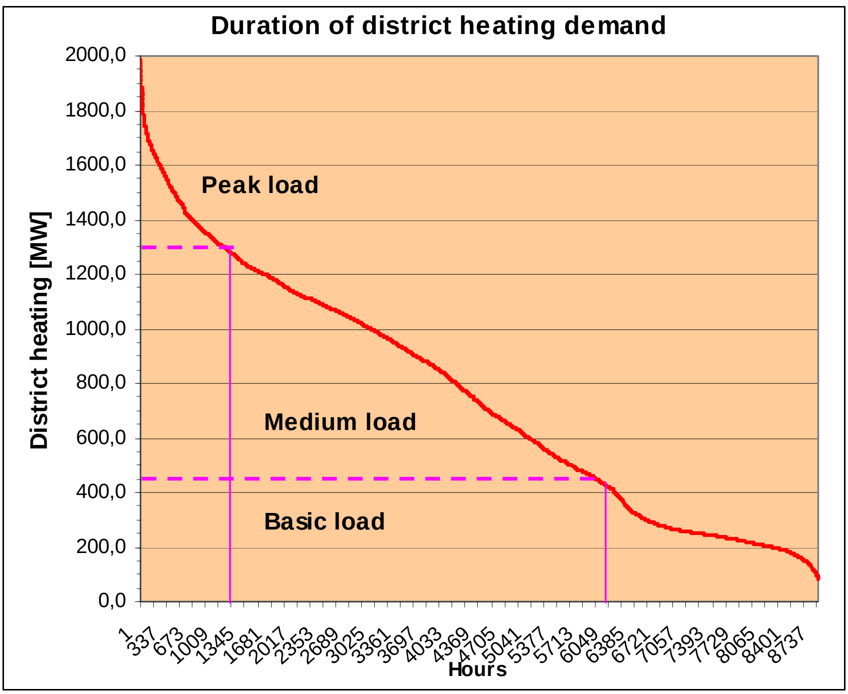


Figure 31. Duration curve of district heating load divided in basic, medium and peak load.

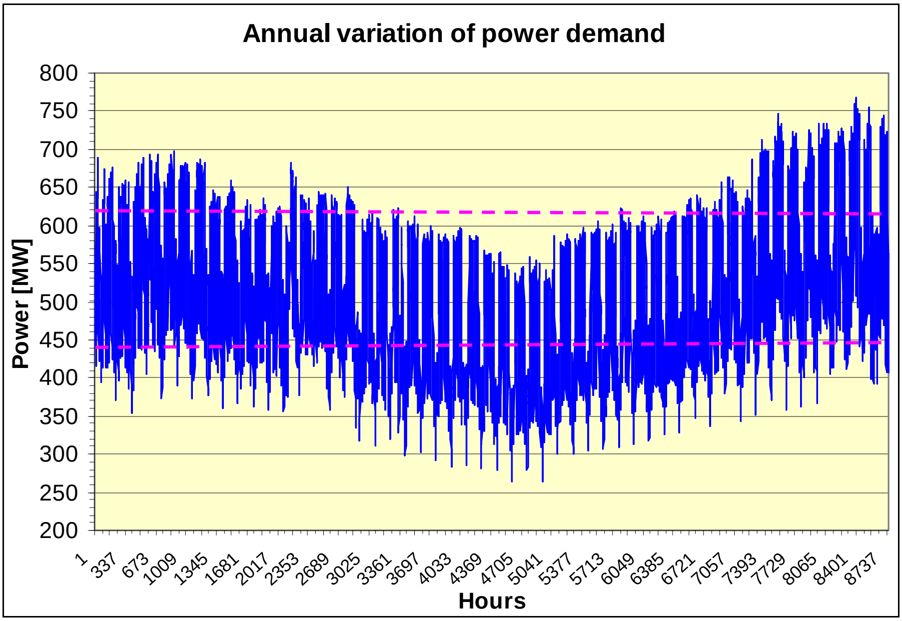


Figure 32. Seasonal and hourly variation of electricity load divided in basic, medium and peak load.

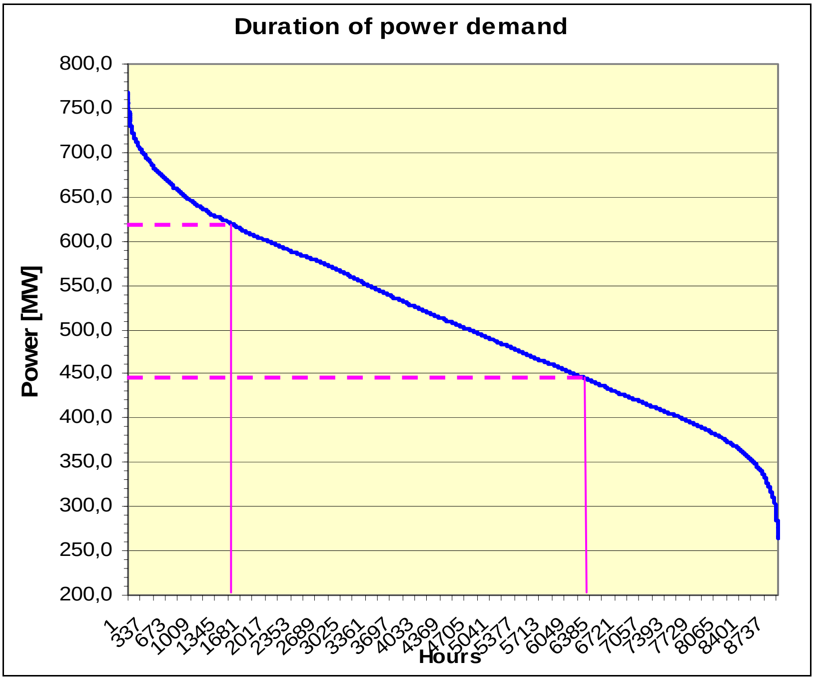


Figure 33. Duration curve of electricity demand divided in basic, medium and peak load.

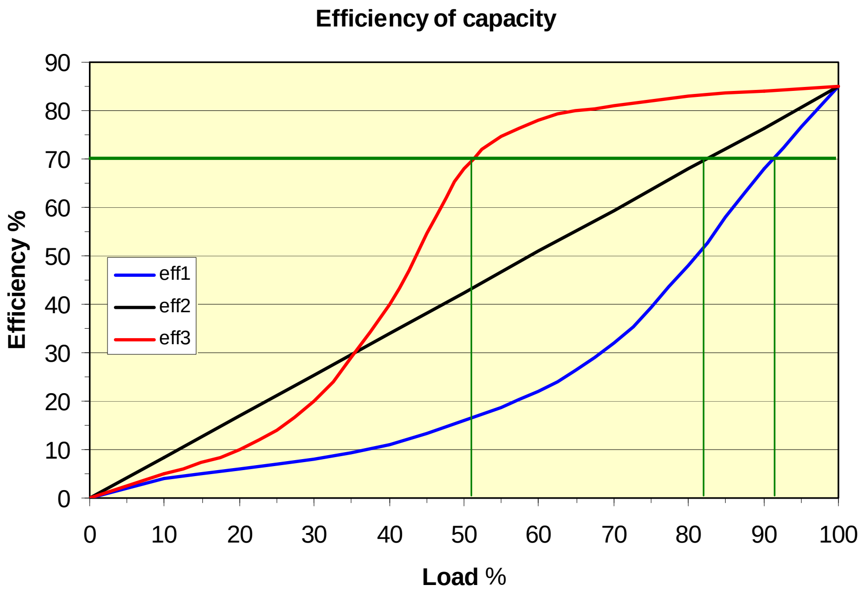


Figure 34. Efficiency as a function of load rate for three types of power plants. (eff1 is peak load, eff2 medium load and eff3 basic load power plant)

7.6 Examples of potential evaluation

7.6.1 EPOLA energy system model

In order to analyse and measure effects of energy efficiency on an energy system, EPOLA model (Energy POlicy Analysis) initially developed for Ministry of Employment and the Economy (formely called Ministery of Trade and Industry) for an energy policy tool, is used to obtain numerical results and to quantify energy efficiency potential. EPOLA model is a dynamic linear optimisation model based on EFOM (Energy Flow Optimisation Model) energy modeling principles (Van Voort et al. 1984). This easy-to-use, robust and modular model operated in Excel spreadsheet environment enables a practical long term cost-optimal analysis of energy policy. Basically EPOLA formulates a structure of an energy system, illustrated in Figure 35, as a linear optimisation problem and produces a feasible cost-minimising solution which portrays a possible future development of the energy system.

Model includes e.g. investments in energy infrastructure; process based pulp and paper industry, energy balances with energy saving measures, and can produce energy efficiency indicators such as primary energy consumption and CO_2 emissions for milestone years defined in the model. Since EPOLA model is Excel based and optimisation is performed in a few minutes, simple sensitivity analysis of an energy system can be performed at ease.

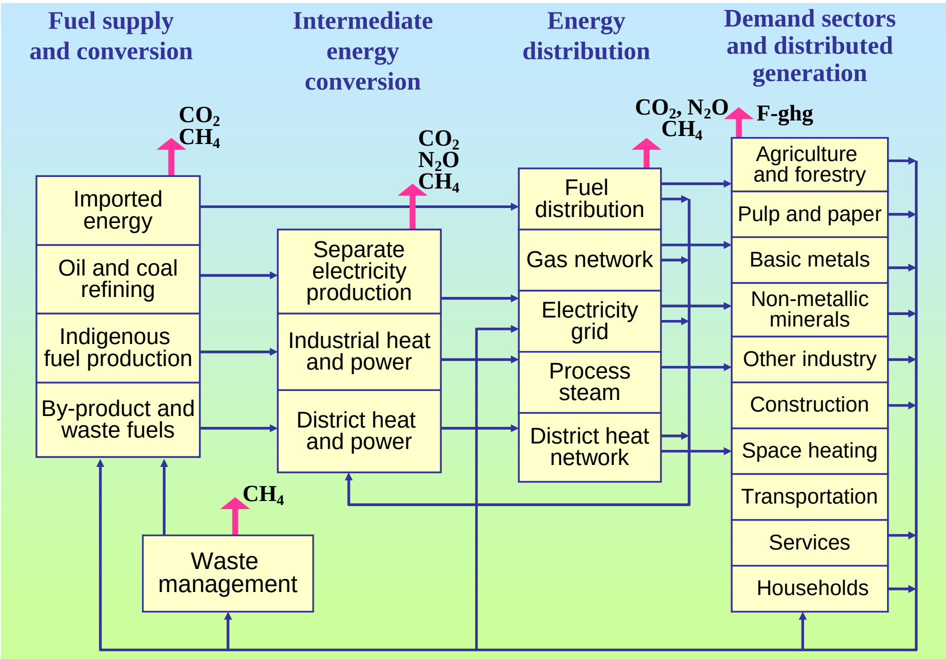


Figure 35. Structure of the energy system used as a basis for EPOLA energy system model.

7.6.2 Sensitivity analysis of effects on energy system

Energy system model described earlier can be used to analyse effects of energy efficiency measures in scope of several years. This energy system based estimation does not merely highlight direct effects of energy efficiency but also indirect systemic effects via finding an optimal development of the energy system. If e.g. industrial energy efficiency measures decrease industrial consumption of effective energy carriers such as industrial steam or electricity, energy system model will adapt to this altered demand with possibly different fuel mix and investments in energy infrastructure. These changes in an energy system will affect primary energy consumption and CO_2 emissions, which are the main efficiency indicators of the energy system, dynamically in the time span of the model.

If effects of these alterations in end use consumption are estimated separately, sensitivity analysis of the energy system may produce surprising results when model adapts to this separate change, coincidently maintaining other end use consumptions and their effects on the energy infrastructure. One simple illustration of this phenomenon is systemic sensitivity of energy efficiency improvements in households and other buildings using district heat. Decreased heat load presents an interesting scenario for energy system sensitivity analysis, since major part (approximately 75%) of district heat is produced in CHP power plants, which produce also electricity for other purposes. This specific property of the energy system leads up to a decreased load of CHP power plants as well. However, in this case of the sensitivity analysis electricity consumption in end use sectors is not assumed to be altered, and at the same time electricity production of CHP plants decreases. Therefore, this consequent scarcity of electricity must be covered by other energy infrastructure, basically condensing power plants. Such a transition in an energy system brings about interesting effects on primary energy consumption and emissions.

In Figure 36 four different developments of a district heat load are illustrated. It has to be noted that baseline curve already involves some improvement in efficiency of district heating use, but other curves related to sensitivity analysis indicate decrease of district heating consumption in the year 2050 from the baseline value. In Figure 37 effects of different heat loads on fuel consumption of condensing and CHP power plants are presented. It is evident that decreasing district heat production decreases load of CHP plants whereas fuel consumption of condensing power increases due to the decreasing electricity production by CHP plants. Therefore, part of electricity production shifts from CHP to condensing power. In Figure 38 effects of this electricity production shift on primary energy consumption and CO_2 emissions are presented. Evidently, energy efficiency measures in buildings connected to district heating decrease primary consumption slightly, since use of final energy is reduced. However, CO_2 emissions seem to increase slightly in time (0.8% in 2050), since condensing power plants use mainly carbon intensive coal or peat instead of biomass or natural gas used mainly by CHP plants. Details of the energy efficiency indicators and effects of district heating load on energy system in year 2050 can be seen in Figure 39 which reveals the multicriteria nature of energy system related efficiency measures.

The preceding sensitivity analysis concerned merely buildings using district heat. Naturally, if efficiency measures are applied to all buildings with net effective heating following trends congruent with Figure 36 (total heating energy in 2050 being 56 551 GWh), effects on primary energy and emissions should be more outward. This is quite evident from Figure 40 and Figure 41 where primary energy consumption and CO_2 emissions decrease as efficiency measures in buildings increase. However, changes are relatively small due to e.g. the future change in heating fuel mix (from oil to DH and biomass), effects of decreasing district heat load examined in Figure 39, and relatively high volume of primary energy consumption and emissions in other sectors. This analysis also indicates that energy efficiency measures in buildings could be prioritised, so that buildings using other heating methods than district heating would have a higher priority, in order to maximise effect of energy efficiency in the case of scarce resources.

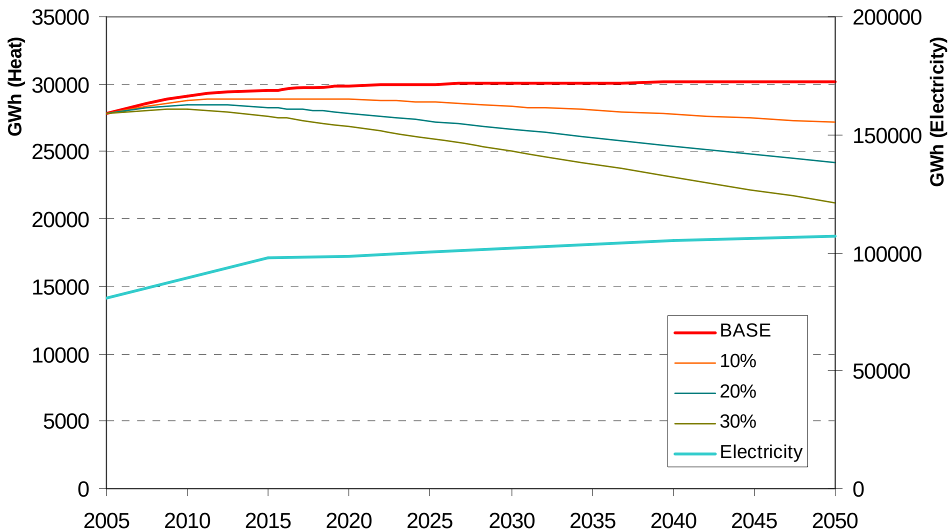


Figure 36. Different developments of district heating consumption in systemic sensitivity analysis.

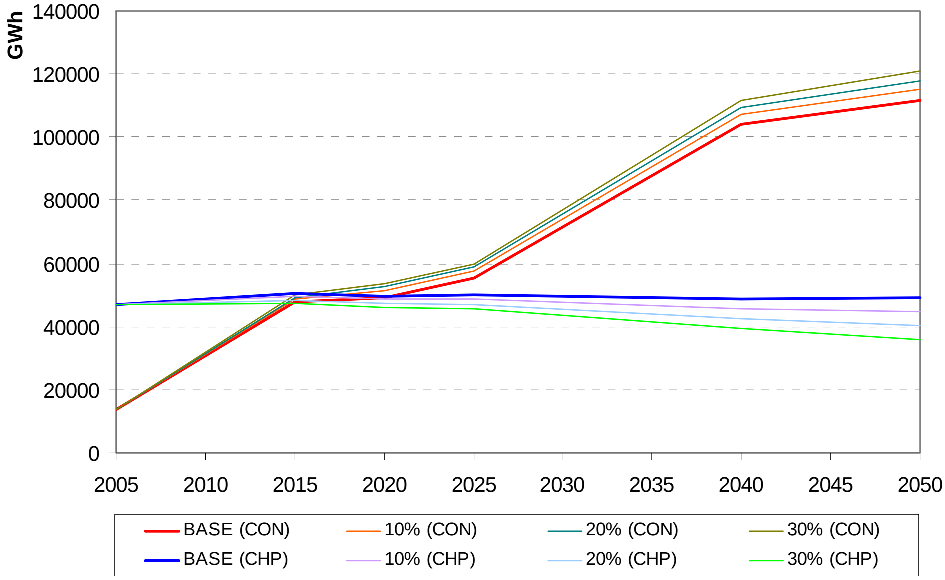


Figure 37. Effects of district heating load sensitivity analysis on fuel consumption of condensing power plants (CON) and CHP power plants (CHP).

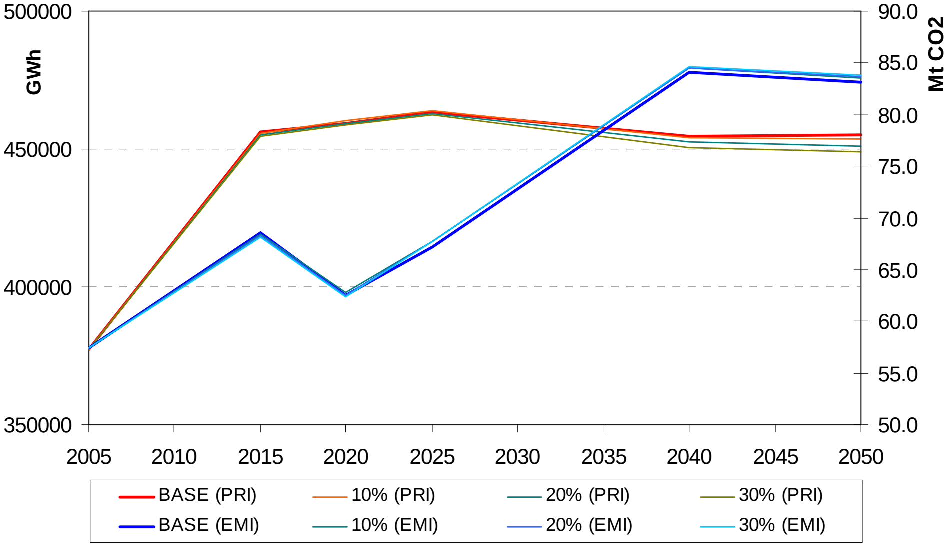


Figure 38. Effects of district heating load sensitivity analysis on primary energy consumption (PRI) and CO_2 emissions (EMI).

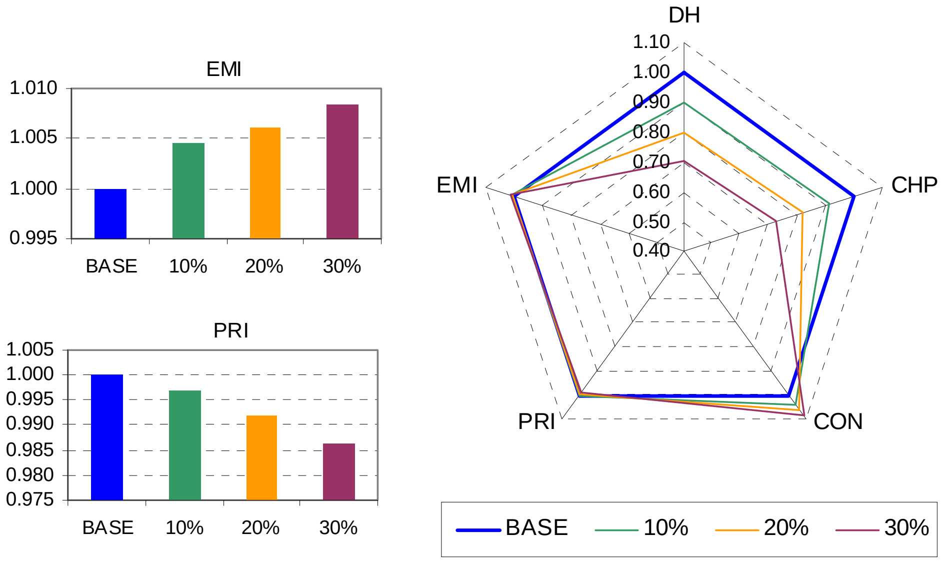


Figure 39. Spider-web type representation of the indicators used in multicriteria analysis in the case concerning district heating load sensitivity effects in the year 2050.

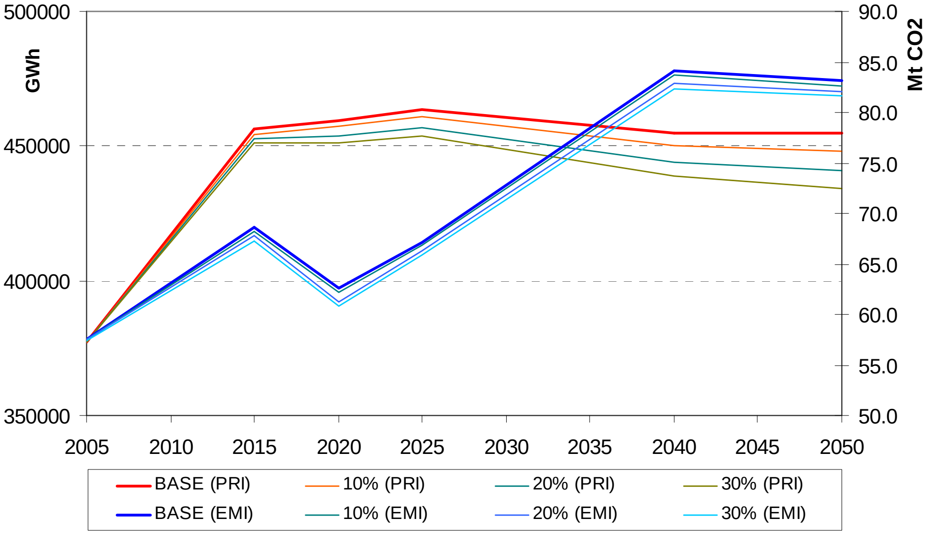


Figure 40. Effects of building heat load sensitivity analysis on primary energy consumption (PRI) and CO_2 emissions (EMI).

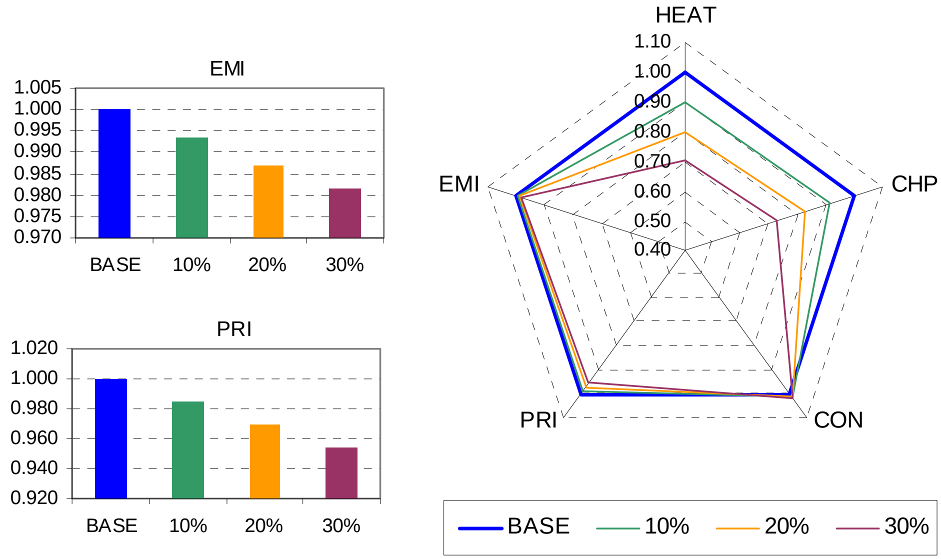


Figure 41. Spider-web type representation of the indicators used in multicriteria analysis in the case concerning building heat load sensitivity effects in the year 2050.

Potential of energy efficiency in energy production infrastructure can be analysed by comparing two scenarios subject to primary energy consumption and emissions. First scenario is the baseline scenario for which the model is calibrated and was used in previous calculations. In the model, energy producing technologies, i.e., different power plants have efficiency values increasing in time based on estimates on potential of technological advance. For example, CHP power plant based on natural gas combined cycle has total efficiency of 89% in year 2005 and 93% in year 2050. This development of efficiency affects main indicators, i.e., primary energy consumption and emissions, and this effect can be calculated by using a second scenario in which efficiency values of all the power plants, including industrial CHP plants and industrial boilers, remain at the year 2005 level for the entire time span.

In Figure 42 difference in primary energy consumption and CO_2 emissions between these two scenarios is illustrated. It is evident that the effect of efficiency improvements of power plants on an energy system is not groundbreaking though significant. In year 2050 primary energy consumption is 3.3% lower due to the efficiency measures whereas emission reduction is 5.9%. This can be interpreted in such a way that Finnish energy sector is already technologically so advanced that efficiency potential of the energy producing infrastructure remains relatively small.

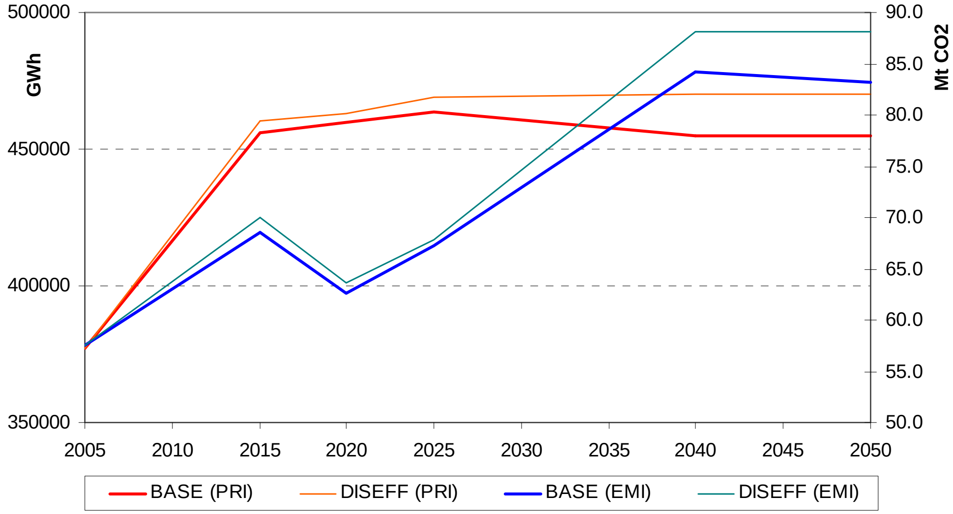


Figure 42. Effects of a scenario disregarding improvements in efficiencies (DISEFF) of energy production infrastructure on primary energy consumption (PRI) and CO_2 emissions (EMI).

7.6.3 Energy efficiency in Finnish district heating including CHP production

The Finnish district heating system is described in this example based on 2007 statistics (Energy Industry, 2007a). The average outdoor temperature was 1.5 °C higher than the long term average temperature in 1971–2000. Monthly average temperature was higher than the long term average except February. Then the outdoor temperature was 4 °C lower than in a normal year.

The total district heat production was 32.3 TWh and electricity through CHP production 14.7 TWh. The total fuel energy used for preceding production was 55.0 TWh. District heating consumption was 30.1 TWh and electricity 87.3 TWh. Loss in heat and electric network was 6.8% in heat and 3.4% in electricity production.

Efficiency of DH suppliers (own and bought energy production) including CHP is presented in Figure 43. The bought energy is chained to the original producer fuels. The average efficiency was 86% in own and 88% in bought DH-energy. Remarkable is that the worst efficiency in own production is 42% and bought production 56%.

Annual fuel factor of heat producers is presented in Figure 44. Also producers, which have not any own DH-network included. The average fuel factor is 1.17 (η = 0.86) whereas maximum factor is 1.81 and minimum 1.01.

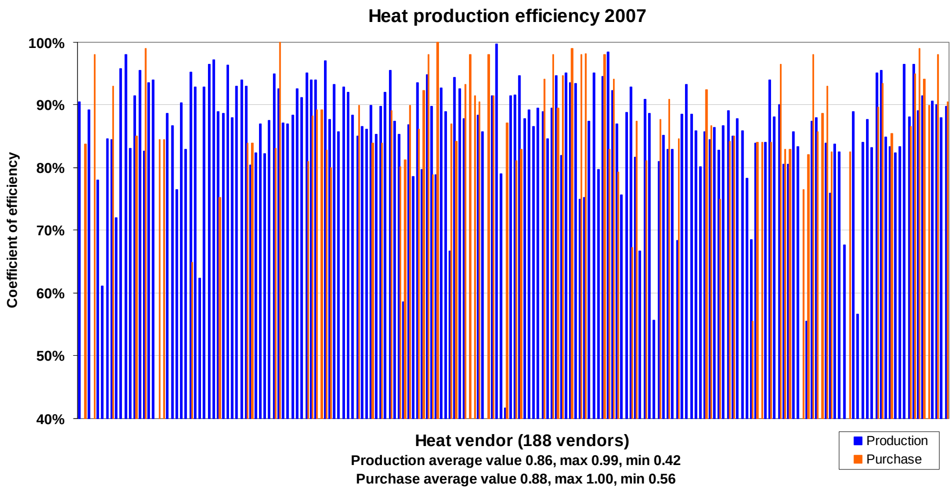


Figure 43. Efficiencies of district heat production by suppliers (own and bought).

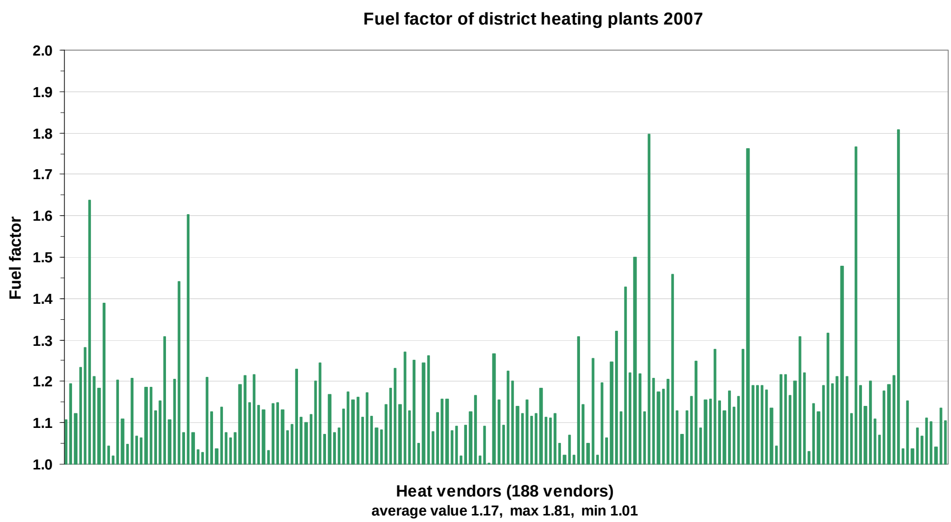


Figure 44. Annual fuel factor of heat production.

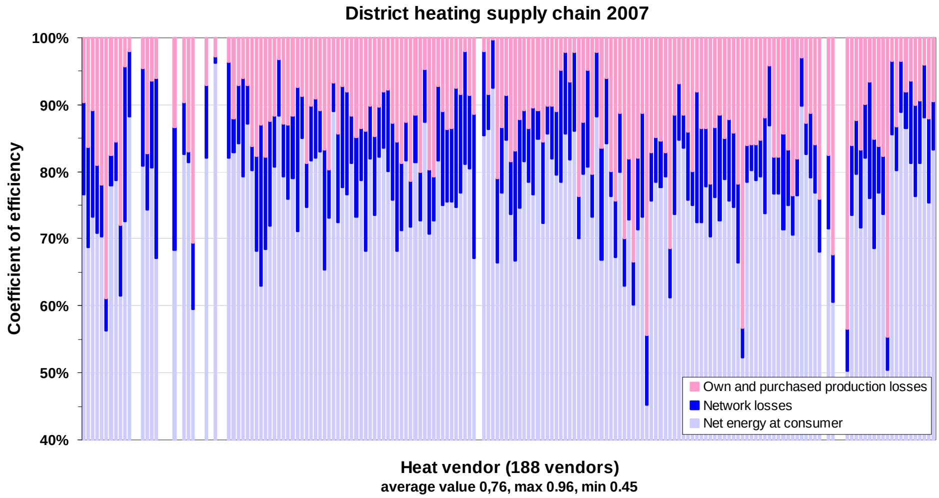


Figure 45. Efficiency of district heating production chains from supply to end users in Finnish DH-systems in 2007.

Annual efficiency of district heating systems in Finland is presented in Figure 45. The energy chain is divided into own production and bought heat energy as well as delivering district heat network. The light blue bulks represent energy efficiency (net energy) at end users. The average energy efficiency at end users is 76% compared to original fuel energy. The maximum efficiency is 96% and minimum 45%. After receiving the heat energy by the consumers the efficiency of building heating systems must be taken into account before serving the indoor temperature to the inhabitants.

Empty columns (Figure 45) mean producers, which have no own DH-network. They own only the DH-production units (boiler and/or CHP) and sell the heat to the local district heating company.

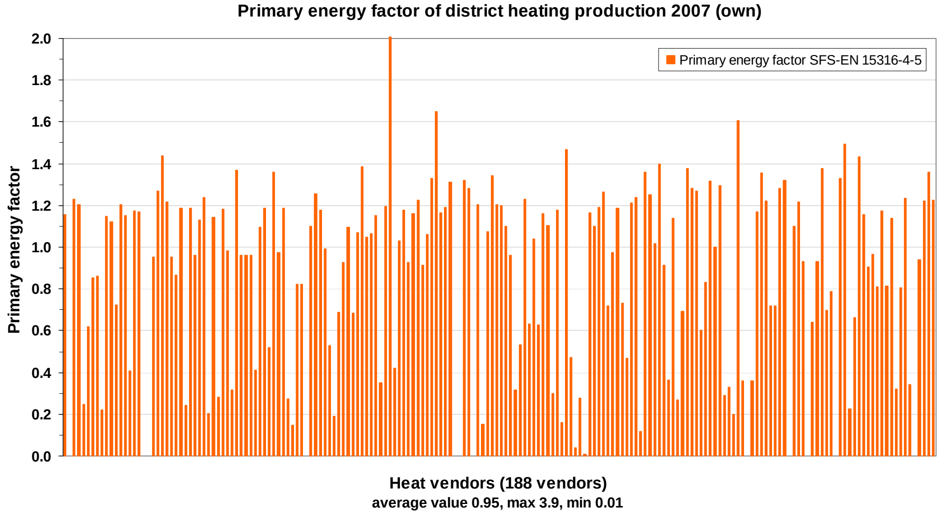


Figure 46. Annual primary energy factors of DH producers based on EN-15316-4-5 standard.

Annual primary energy factors of Finnish district heat producers in 2007 are presented in Figure 46 based on EN standard 15316-4-5. The average primary energy factor is 0.95, and maximum is 3.9 and minimum 0.01. The factor is calculated as it is presented in Chapter 3.3. If the producer has CHP unit, CHP electricity compensates amount of fuel energy for district heating with the factor 2.5.

Annual primary energy factor of DH suppliers is presented in Figure 47. The primary energy factor is the same as in Figure 46 except for the bought energy, which is chained from DH supplier to the original producer. The producer can be another DH supplier, sawmill or pulp & paper factory. The annual average primary energy factor is 0.69, maximum 2.2 and minimum -1.4. If producer has CHP production and part of heat is sold to local DH -company, the primary energy factor can be negative when supplier's CHP electricity multiplied by 2.5 decreases the corresponding heat primary energy of DH -company. This gives the right signal in energy production, because heat producer can generate more electricity in CHP and sell the extra useful heat to a local DH supplier.

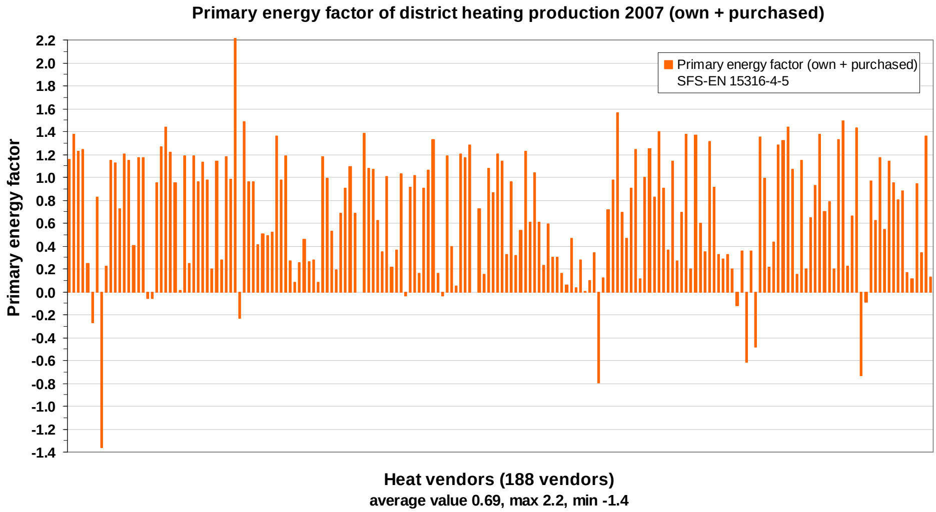


Figure 47. Annual primary energy factors of DH suppliers based on EN-15316-4-5 standard including supplier's own production and bought DH energy.

7.6.4 Paper mill integration to district heating system of local community

UPM-Kymmene Kymi paper mill is located at Kuusankoski, Kouvola about 140 km North-East of Helsinki. The paper mill uses wood more than 2 million m^3/a as a raw material for producing chemical pulp. The capacity of the paper production is 840 000 ton/a and other products 12 000 ton/a including tall oil and turpentine. Nearly all electricity needed for pulp and paper production is generated by the mill itself and by Kymin Voima. The paper mill produces also bark as a by-product; which is used as a fuel in Kymin Voima.

Kymin Voima Oy power company supplies power (85 MW capacity) and process steam (140 MW) to UPM paper mill and district heat to the district heating companies (52 MW) at Kuusankoski and Kouvola. The power plant is also located at the paper mill site. Fuels are mainly bark and wood residuals from the paper mill and in addition peat, sawdust, and sludge in total effective value of 1 000 GWh/a. The share of wood based fuel is more than 85%. The peat is collected and transported within about 100 km radius around the power plant site.

Process schema of the power plant and paper mill integration is presented in Figure 48. The dash line separates Kymin Voima from UPM-Kymmene Kymi paper mill. Energy production of Kymin Voima is presented in 2005–2008 in Figure 49.

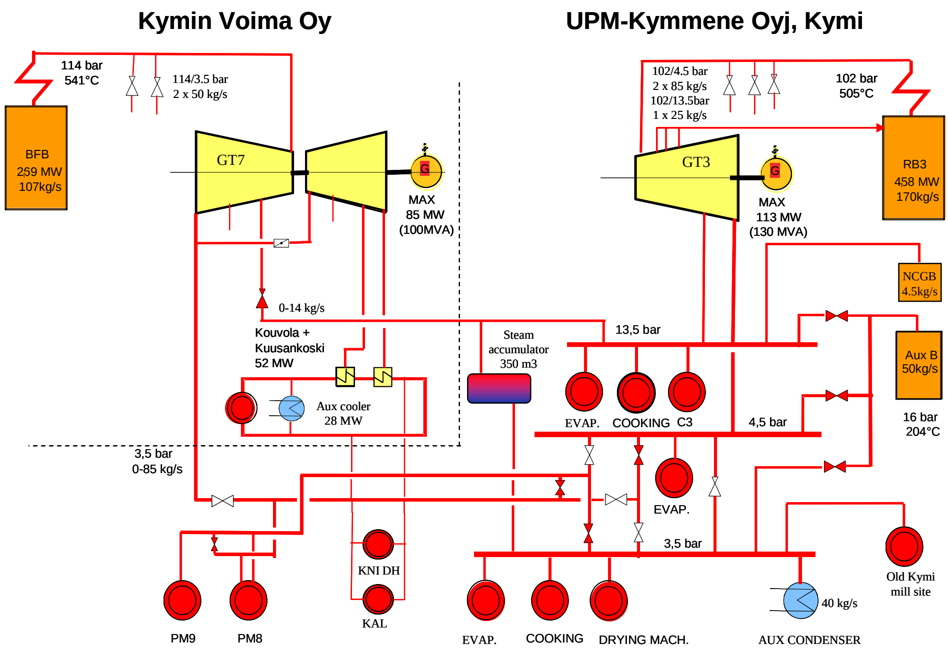


Figure 48. Process schema integration of the power plant and the paper mill.

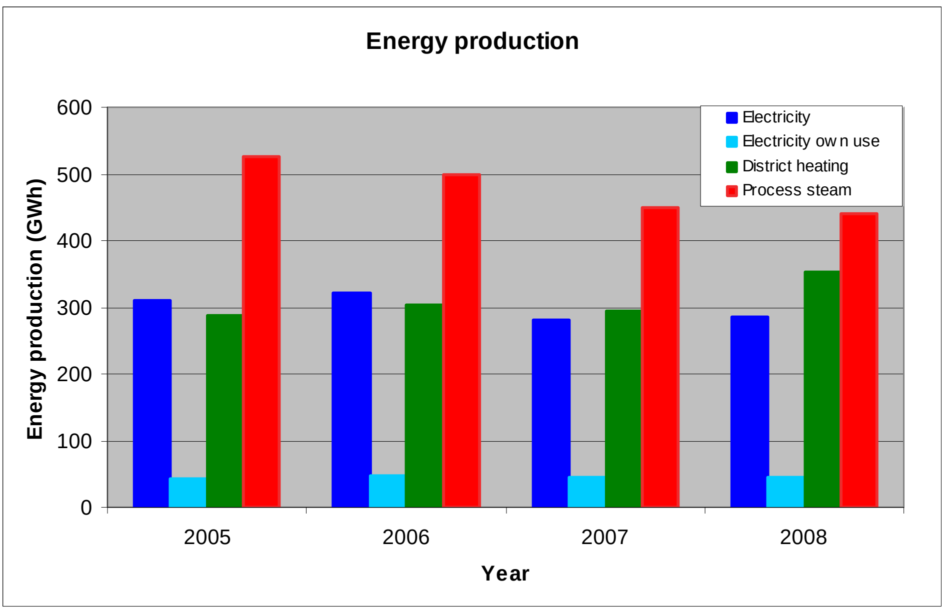


Figure 49. Energy production of Kymin Voima CHP plant in 2005–2008.

Steam supply to UPM Kymi paper mill has decreased during 4 years and electricity generation and district heat is near 300 GWh/a. Electricity for own use was about 4.2% of the sum of electricity, district heat, and steam production.

The district heat is sold through KSS Energy to Kouvola (VARI) and Kuusankoski (KAL) amounting to about 2/3 of the total district heating demand in those two towns.

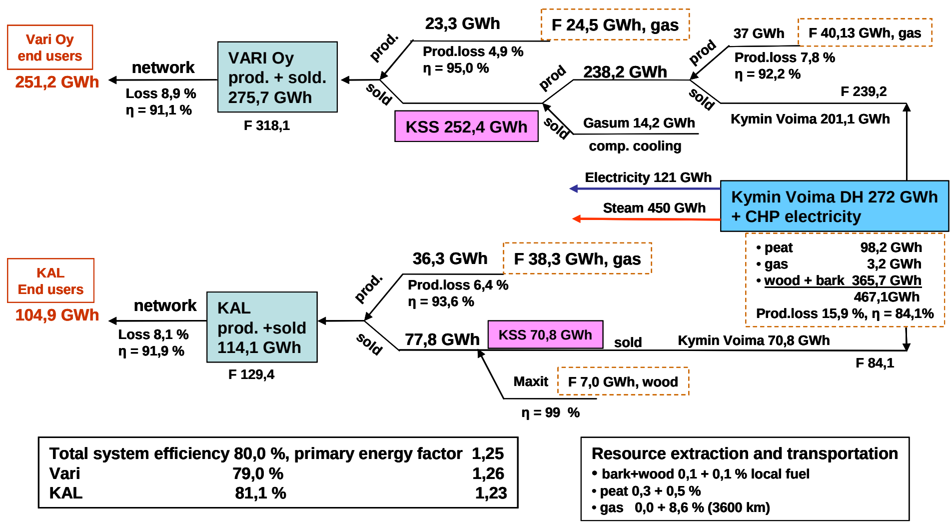


Figure 50. District heating chain from CHP plant to end users.

A district heating supply chain from Kymin Voima to end users in Kouvola and Kuusankoski is presented in Figure 50. The numbers in the Figure 50 represents energy supply and consumption in 2007.

The total efficiency of district heating is 80% including also own production of KSS Energy, Kouvola and Kuusankoski. The primary energy factor is 1.25. The annual efficiency of CHP for electricity and district heat production is 84.1%. The electricity production is 161 GWh/a connected to steam production for UPM paper mill. In addition to district heat supply to Kouvola and Kuusankoski by Kymin Voima, district heat is supplied also to UPM paper mill site 22 GWh in 2007. Peat fuel extraction and transportation energy has spent about 0.8% of fuel energy value, which increases the total cost of peat. The gas is supposed to be the Siberian natural gas with the transportation of 3 600 km. Bark and wood residuals are transported on the belt conveyor from the paper mill.

The main process values in Kymin Voima CHP plant are shown in Figure 51. The plant production follows the steam demand in the paper mill and the power generation adopts oneself. District heat is in connection to power generation except time periods, when steam demand strongly decreases.

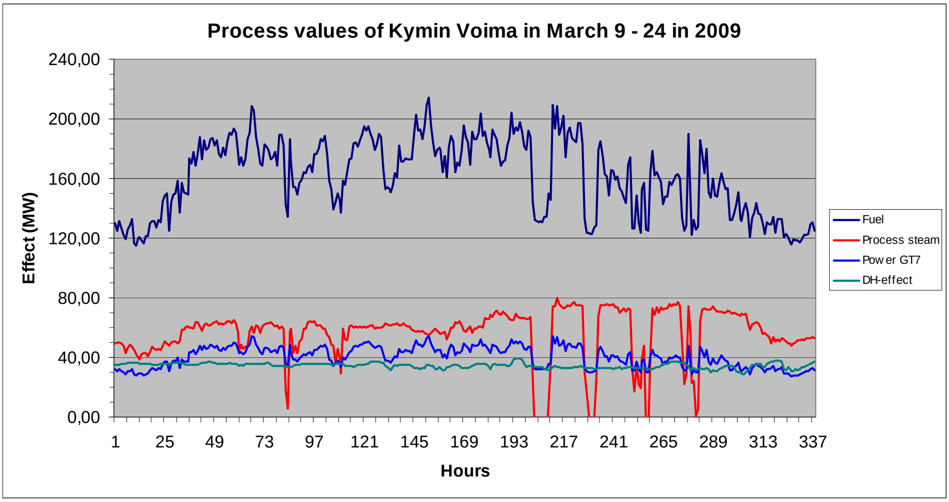


Figure 51. Process values of Kymin Voima CHP plant between March 9–24 in 2009.

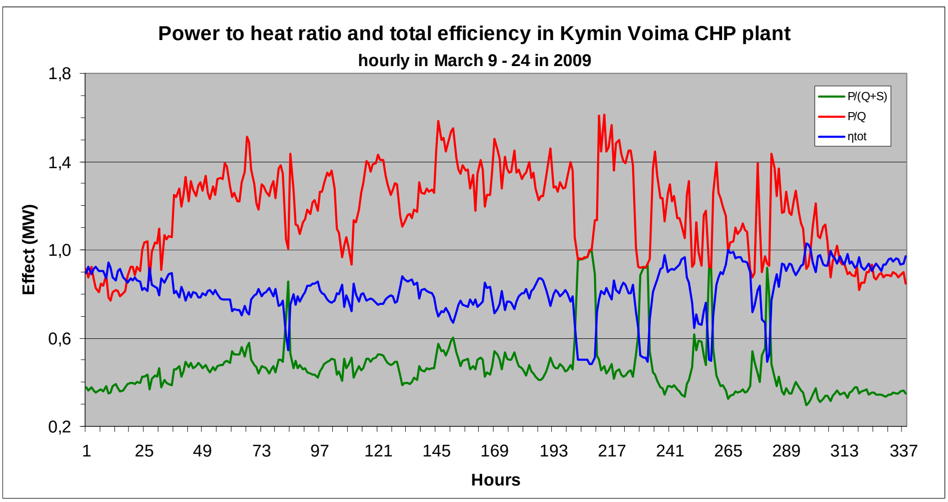


Figure 52. Power to heat ratio and total efficiency of Kymin Voima CHP plant hourly in March 9–24 in 2009.

Power (P) to heat ratios (district heat Q, district heat Q + steam S) and total efficiency (η_{tot}) of Kymin Voima CHP plant are shown in Figure 52. As seen the total efficiency varies all the time and reacts strongly to steam demand decreasing. The power to heat ratio (DH+steam) of the CHP plant increases at the same time because of bypassing of district heating. Power generating decreases following the steam demand. The power to heat ratio (DH) of the CHP plant is more than one, because steam demand generates also power. The partly load efficiency of the power plant is not useful to utilise for energy chain evaluating based on steady state calculation hourly because of delays in the process. Then we need a dynamical model of the power plant, the steam system of the paper mill, and the district heating system.

As we can see in the scheme in the Figure 50 the paper mill integration to a regional district heating system is very useful. A large share of the fuels (bark and wood residues) is as a by-product of pulp and paper mill. Fuel transportation is connected to paper raw material supply. More fuel (peat, saw dust and wood residual) is needed about 20–25%. Also all the fuel except peat are CO_2 free and save other fuel supply of community around the paper mill.

8. Conclusions

Buildings

Buildings have a relatively high potential for energy efficiency improvements compared to other sectors of the economy. Indicators are needed to measure both current energy efficiency and improvement potential. Various indicators serve different purposes and interests in the buildings sector depending on the needs of the indicator's user, who may range from the user of the building to the regulator, just mention to two of the typical stakeholders of a building. Defining a universal indicator to cover all needs is not possible. Therefore an array of indicators is suggested – what indicator to use depends on the situation and the objectives of the analysis.

Specific energy consumption (SEC), measured in kWh/m^2, is a good general purpose indicator already commonly in use. However, in its plain form it does not take into account embodied energy or primary energy consumption, and a method to include these in SEC is suggested. To take into account the ratio of use and idle time of the building SEC_{UR} or SEC adjusted for utilization rate is defined. Energy intensity of usage (EIU), measured in kWh per person hours, is an indicator best suited for measuring the effects of efficient use of space within a limited group of similar buildings, whereas economic energy intensity (EEI) measures energy consumption (kWh) per market value of the building measured in rent (€). Finally, energy performance index (EPI) is a benchmarking indicator that shows the ratio of a building's energy consumption to what would be achievable with the best available technology.

These indicators cover most of the different aspects of energy efficiency in buildings important to the stakeholders. They should be used as a mix and none of the indicators should be seen as the final word on energy efficiency by itself. Quality of the built environment is an important factor missing from the indicators, being too complicated an issue to be reduced into a single numeric term. Rather, it is strongly recommended, that quality should be measured with appropriate indicators of its own whenever energy efficiency is measured.

Investments in energy efficient buildings are an economically sound and effective way to save energy. By 2020 the measures studied would allow cost-effective annual energy savings of 7 TWh, which represents more than a 10% drop compared to BAU. By 2050 savings of about 40% are projected. With a more rapid pace of development the results could double to about 25% by 2020 and over 50% by 2050. Details on how the energy savings could be achieved are provided in Appendix B.

So far only partial analysis of the energy efficiency potential has been completed. Further studies should combine the study of buildings with the study of communities and energy system. Changes in buildings are at interplay with the other fields and a lot depends on how the system as a whole is able to adapt to increasing efficiency. Thus the pitfalls of partial optimization could be explored. Moreover, the theory and methodology of energy efficiency indicators and calculations should be developed further to ensure the validity of efficiency calculations. Also, the present set of indicators could be developed to be better adapted to specific cases.

Communities

Energy use in communities (city regions, cities, towns and other urban areas as well as rural communities) takes place in both buildings and infrastructure, during construction, use, maintenance, repair, renovation, demolition, and recycling as well as during transportation of people and goods. That is why energy efficiency of communities must be a composition of energy used during the life-cycle of several physical elements brought together for the community.

This research has collected and analysed previously split information on measuring, indicators, and potentials of energy efficiency of communities. The versatile scale of the research has been of great significance. For example system boundaries of measuring energy efficiency of communities have been considered with connections to other sectors and their interfaces.

System boundaries of measuring energy efficiency of communities are not unambiguous and they can be adapted at need. System boundaries can be defined by areal or functional basis.

Energy efficiency of communities can be defined as a ratio between an input of energy consumption or emissions, and an output of services, such as number of inhabitants and workplaces or floor square metres.

Indicators of energy efficiency of communities have been described generally. They can be utilized in different considerations of energy efficiency of communities. There are several energy efficiency indicators which consist of different parts and phases. Indicators complete each other.

Experimental calculations were made for the basis of an energy efficiency potential calculation method for communities. According to research material and calculations communities may have a relatively high potential for energy efficiency improvements. Potential seems to be highest in the operation phase of structures and in transportation. Measuring energy efficiency and potentials of communities are connected strictly to other sectors of the research: buildings, energy production, industry, and logistics.

In order to improve energy efficiency of communities attention should be paid especially on location and other urban form choices, which affect transportation need and modes and thereby energy use of transportation. Loose urban form affects substantially wideness of infrastructure. Energy consumption of buildings forms most of energy consumption of communities and improving their energy efficiency has a significant role in improving energy efficiency of communities. In addition to new structure energy efficiency of existing built environment should be improved.

Further research needs to concern further development of energy efficiency measuring and potential calculations especially integrated with other sectors. Target areas should be both planning of new areas and development of existing built environment, renovation, complementary building, and infill development. Energy efficiency potential of the whole urban form development of Finland would promote decision making for national and international work for combating climate change.

Energy Systems

Energy chain is an illustrative way to look at the energy efficiency and compare different alternatives. The comparing work has to include all the possibilities, which have impact to the results. Different production and consumption sectors are effectively integrated to each other, so interfaces have to be taken care of between them. Higher energy efficiency needs investments preventing many times to carry out technical improvements.

Energy production chain has many indicators, which can be presented in consumption/produced-MWh a.k.a one produced energy unit needs fuel, transportation, service, and human resources as well as transfer losses, emissions, and wastes. Indicator of quality of products, availability, reliability and on-peak period has to be present in other way. Indicators during building as material/produced-MW that is one built power unit needs materials like concrete, steel, copper, plastic, glass, etc. Energy is also required when building. The indicators of operating and building can be compared to each other in different energy production alternatives or to make bench-marking with same kind and age energy production somewhere else.

The best way to spare energy is in consumption, because it has an impact through the whole energy chain far to the primary energy source. Spared energy does not always have impacts to decreasing of the emissions. That is why the total impacts through the whole energy chains and cross-impacts to other sectors have to be evaluated.

From the environmental point of view the non-emission and natural energy production (solar, wind, hydro, tidal, wave, etc.) would be the best alternative in other words non-burn alternative. Also the renewable fuels like wood and energy wastes are possible, if carbon dioxide balance is not disturbed. The quality of energy (exergy) should be underlined in the energy chains. Sparing of electricity is more efficient than sparing of heat because of higher exergy content of electricity.

All the loss flows in energy production should be cut and returned to the process or used as an energy source for another process. The theoretical limit for temperature utilised is outdoor temperature. In Northern countries utilising of the low temperatures has good possibilities because of low outdoor temperature (< 0 °C) in the winter heating seasons.

The design of CHP (simultaneous combined heat and power production) should be changed to correspond better to supply district heating temperature in the future. The steam expansion in the CHP turbine could be prolonged to give lower temperature for district heating and lowering the pressure. Higher power-to-heat ratio of CHP gives more electricity. The district heating network should be designed “tighter” and insulated enough as well as to guarantee enough drop of DH-temperature at consumers.

9. Summary

Buildings

The building sector is a major consumer of energy with about 38% of the world's final energy being consumed in residential and commercial buildings. Relatively high savings potentials, if not the highest, have been identified in buildings compared to the other sectors of the economy. The realisation of these potentials is dependent on the various stakeholders of buildings, such as the user of the building, the owner, and the regulator, just to mention a few.

Measuring energy efficiency in buildings is complicated by the fact that the various stakeholders have differing interests regarding energy efficiency. Therefore, no single indicator can be devised that could serve all needs. Rather a set of indicators is suggested, whereby the right combination of indicators can be chosen for each purpose. In addition of energy efficiency, quality of the indoor environment should be measured at the same time, as it is not factored in the indicators.

Investments in energy efficient buildings are a cost-effective way to save energy. By 2020 the measures studied would allow energy savings of 10–25% compared to no changes in buildings. By 2050 savings of about 40–50% are projected.

Communities

Energy use in communities (city regions, cities, towns and other urban areas as well as rural communities) takes place in both buildings and infrastructure, during construction, use, maintenance, repair, renovation, demolition, and recycling as well as during transportation of people and goods. That is why energy efficiency of communities must be a composition of energy used during the life-cycle of several physical elements brought together for the community.

Energy efficiency of communities can be defined as a ratio between an input of energy consumption or emissions, and an output of services, such as number of inhabitants and workplaces or floor square metres.

There are several energy efficiency indicators which consist of different parts and phases. Indicators complete each other.

Communities may have a relatively high potential for energy efficiency improvements. Potential seems to be highest in the operation phase of structures and in transportation. Measuring energy efficiency and potentials of communities are connected strictly to other sectors of the research: buildings, energy production, industry, and logistics.

Energy systems

Energy systems consist of many energy chains or routes, which include alternative processing of energy raw materials and energy production possibilities, distributions, and finally to end use as electricity and heat or combination of them. Almost all the energy raw materials have alternative routes, which can be divided and joined together again on the route to the end use.

The best way to spare energy is in consumption, because it has an impact through the whole energy chain far to the primary energy source. Spared energy does not always have impacts to decreasing of the emissions. That is why the total impacts through the whole energy chains and cross-impacts to other sectors have to be evaluated.

All the loss flows in energy production should be cut and returned to the process or used as an energy source for another process. The theoretical limit for temperature utilised is outdoor temperature. In Northern countries utilising of the low temperatures has good possibilities because of low outdoor temperature (< 0 °C) in winter heating seasons.

The design of CHP (simultaneous combined heat and power production) should be changed to correspond better to supply district heating temperature in the future. The steam expansion in the CHP turbine could be prolonged to give lower temperature for district heating and lowering the pressure. Higher power-to-heat ratio of CHP gives more electricity. The district heating network should be designed “tighter” and insulated enough as well as to guarantee enough drop of DH-temperature at consumers.

References

Ahtila, P., Tuomaala, M., Siitonen, S., Kalenoja, H., Rantala, J., Kallionpää, E., Sipilä, K., Wahlgren, I., Shemeikka, J., Forsström, J., Tuominen, P., Halonen, M., Rämä, M., Pursiheimo, E. & Lahti, P. (2009). Measuring and potentials of energy efficiency (EPO). Energiatehokkuuden mittarit ja potentiaalit. In: Veijonen, K., Holviala, N. & Seilo, M. (eds.) ClimBus – Business Opportunities in the Mitigation of Climate Change 2004–2008. Final Report. Tekes Programme Report 4/2009. Helsinki 2009. Pp. 386–399.

APEC (2000). Energy Efficiency Indicators. Asia Pacific Energy Research Centre, Tokyo.

EEA (2000). Are we moving in the right direction? European Environment Agency Environmental Issue Report No. 12, Copenhagen.

Energy Industry (2007a). District heat statistic 2007. 69 p.

Energy Industry (2007b). Energy statistics 2007.

EN standard 15316-4-5 (2008). Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 4–5: Space heating generation systems, the performance and quality of district heating and large volume systems.

European Commission (2006). Action Plan for Energy Efficiency: Realising the Potential. COM(2006)545, Brussels.

Guinée, J. (2002). Handbook on Life Cycle Assessment. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Haas, R. (1997). Energy efficiency indicators in the residential sector. Energy Policy, Vol. 25, Nos. 7–9, pp. 789–802.

Hall, D. (2004). External Costs of Energy. Encyclopedia of Energy. Elsevier, San Diego.

Hammond, G. & Jones, G. (2007). Inventory of Carbon & Energy. University of Bath. http://people.bath.ac.uk/cj219/.

Harmaajärvi, I., Heinonen, S. & Lahti, P. (2004). Urban form, transportation and greenhouse gas emissions. Experiences in the Nordic countries. Espoo, Finland, 2004. VTT Building and Transport. Research report RTE 2108/04. The Nordic Council of Ministers. Copenhagen, Denmark. TemaNord 2004:540.

Harmaajärvi, I., Huhdanmäki, A. & Lahti, P. (2001). Yhdyskuntarakenne ja kasvihuonekaasupäästöt. Urban form and greenhouse gas emissions. Helsinki, Finland. The Finnish Environment 522. Ministry of the Environment. Edita Prima Ltd. (In Finnish, abstract in English and Swedish.)

Harmaajärvi, I., Huhdanmäki, A. & Lahti, P. (2002). Urban form and greenhouse gas emissions. Summary. Helsinki, Finland. The Finnish Environment 573. Ministry of the Environment. Edita Prima Ltd.

Hastings, R. (2008). Primary Energy and CO_2 Conversion Factors. International Energy Agency Solar Heating and Cooling Programme Task 28.

Heinonen, S., Kasanen, P. & Walls, M. (2002). Ekotehokas yhteiskunta. Ympäristöklusterin kolmannen ohjelmakauden esiselvitysraportti. Ympäristöministeriö. Suomen ympäristö 598. (In Finnish)

Heljo, J. (2005). Rakennusten energiatehokkuusindikaattoreiden kehittämisen perusperiaatteet. Tampere University of Technology. (In Finnish)

Heljo, J., Nippala, E. & Nuutila, H. (2005). Rakennusten energiankulutus ja CO_2-ekv päästöt Suomessa. Report 2005:4, Institute of Construction Economics, Tampere University of Technology.

IEA (1997). Indicators of Energy Use and Efficiency: Understanding the Link between Energy and Human Activity. International Energy Agency, Paris.

IEA (2008). Worldwide Trends in Energy Use and Efficiency. International Energy Agency, Paris.

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.

KTI (2010). Vuokran muodostuminen. KTI Institute for Real Estate Economics, Helsinki. http://www.kti.fi/kti/doc/palvelut/kasitteet/vuokran_muodostuminen.pdf. (In Finnish)

Lahti, P. & Moilanen, P. (2010). Kaupunkiseutujen yhdyskuntarakenne ja kasvihuonekaasupäästöt. Kehitysvertailuja 2005–2050. Urban land use patterns and greenhouse gas emissions in Finland 2005–2050. The Finnish Environment 12/2010. Ministry of the Environment. Helsinki 2010. (In Finnish, abstract in English and Swedish.)

Martinkauppi, K. (ed.) (2010). ERA17 – Energiaviisaan rakennetun ympäristön aika 2017. For an energy-smart built environment 2017. Ministry of the Environment, Sitra, Tekes. Helsinki 2010.

Ministry of Employment and the Economy (2009). The report of the Energy Efficiency Committee: Proposal for energy saving and energy efficiency measures. Helsinki.

Motiva (2007). Energy Efficiency Policies and Measures in Finland, Helsinki.

Motiva (2009). Kulutuksen normeeraus. http://www.motiva.fi/kulutuksennormitus.

Mäkinen, T., Soimakallio, S., Paappanen, T., Pahkala, K. & Mikkola, H. (2006). Green house gas balances and new business opportunities for biomass-based transportation fuels and agrobiomass in Finland. VTT Research Notes 2357. http://www.vtt.fi/inf/pdf/tiedotteet/2006/T2357.pdf.

Nuutila, H. (2008). Data obtained from the EkoREM model. VTT, Tampere.

Patterson, M. (1996). What is energy efficiency? Energy Policy. Vol. 24, No. 5, pp. 377–390.

RIL (2001). Rakenteiden elinkaaritekniikka RIL 216-2001. Suomen Rakennusinsinöörien Liitto RIL, Helsinki. (In Finnish)

Rogers, E. (1962). Diffusion of innovations. Free Press, London, NY, USA.

Statistics Finland (2009). Buildings and free-time residences. Statistics available at http://www.stat.fi/til/rakke/index_en.html.

Tuomaala, M. (2007). Conceptual Approach to Process Integration Efficiency. Doctoral dissertation. Otamedia, Espoo.

Tuomaala, M. (ed.) (2010). Energiatehokkuuden mittarit ja potentiaalit. Tutkimuksen väliraportti sisältäen sektorikohtaiset kirjallisuuskatsaukset. Espoo 1.9.2010. (In Finnish)

Tuomaala, P. (2007). Rakennusten energiankäyttö – matalaenergiatalot. Presentation for the Finnish Association of Architects. http://www.safa.fi/sivu.php?cat=1&sel=33&sivu=409.

Tuomaala, P. (2008). Personal communication on 14.1.2008.

Tuominen, P. (2008). The Potential Effects of Low Energy Buildings on the Finnish National Economy. Master's thesis. Helsinki University of Technology, 2008.

UNSD (2009). UNSD Environmental Indicators, United Nations Statistical Division Environment Statistics. http://unstats.un.org/unsd/ENVIRONMENT/qindicators.htm.

USDOE (1995). Measuring Energy Efficiency in the United States' Economy: A Beginning. Energy Consumption Series DOE/EIA-0555(95)/2, US Department of Energy, Washington, DC.

Vainio, T. et al. (2002). Korjausrakentaminen 2000–2010. VTT Tiedotteita 2154, Espoo. http://www.vtt.fi/inf/pdf/tiedotteet/2002/T2154.pdf. (In Finnish)

Virtanen, K. et al. (2005). Asukaslähtöisen perusparantamisen kehitystarpeet. Environmental administration, Helsinki.

Voort, E. van der, Donni, E., Thonet, C., Bois d'Enghien, E., Dechamps, C. & Guilmot, J.F. (1984). Energy Supply Modelling Package EFOM-12C Mark I, Mathematical description. Louvain-la-Neuve, Cabay: Commission of the European Communities, EUR-8896.

Wahlgren, I. (2009). Assessing Ecological Sustainability in urban planning – EcoBalance model. In: Koukkari, H. & Nors, M. (eds.) Life Cycle Assessment of products and Technologies. LCA Symposium. VTT Symposium 262. Pp. 106–121.

Appendix A: Summary of results of the potential evaluation for an apartment building

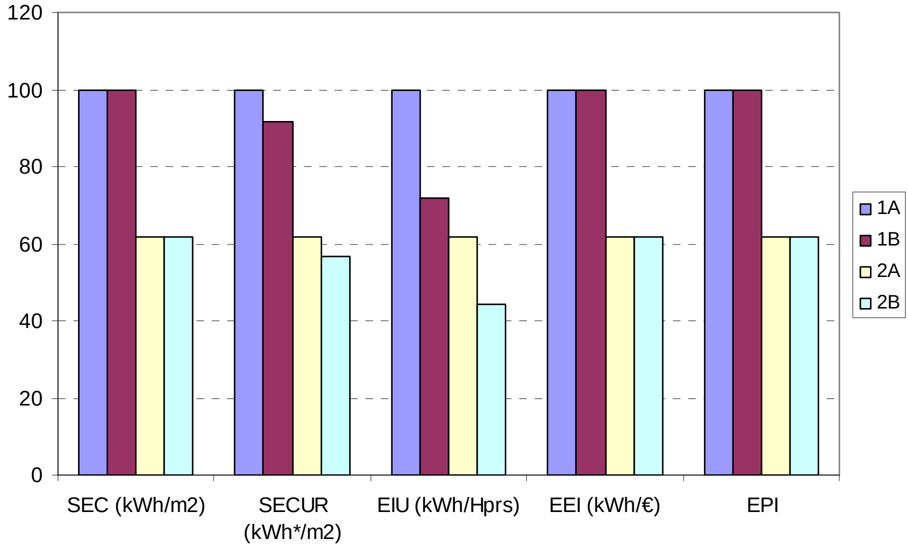


Figure A1. The index (1A = 100) of the simulation results for the four cases taking into account embodied energy and weighting for primary energy.

Table A1. Simulation results for the four cases not taking into account embodied energy or weighting for primary energy.

	1A	1B	2A	2B
SEC (kWh/m^2)	193	193	94	94
SEC_{UR} (kWh^*/m^2)	210	193	102	94
EIU (kWh/h_{pers})	1.54	1.11	0.75	0.54
EEI (kWh/€)	1.65	1.65	0.80	0.80
EPI	2.06	2.06	1.00	1.00

Table A2. Simulation results for the four cases taking into account embodied energy and weighting for primary energy.

	1A	1B	2A	2B
SEC (kWh/m^2)	253	253	156	156
SEC_{UR} (kWh^*/m^2)	276	253	171	156
EIU (kWh/h_{pers})	2.02	1.45	1.25	0.90
EEI (kWh/€)	2.16	2.16	1.34	1.34
EPI	1.62	1.62	1.00	1.00

* Adjusted for utilization rate

Appendix B: Summary of results of the potential evaluation in the Finnish building stock

The following graphs show the forecast development of the building stock in the three scenarios in 1 000 m^2. The colours indicate the following construction years or types of buildings:

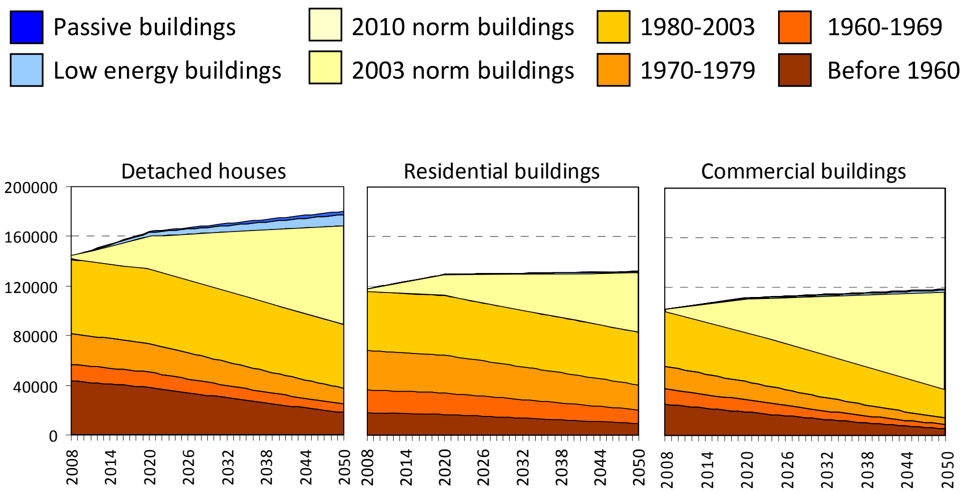


Figure B1. Business as usual (BAU) has the norm building of 2003 as the dominant building type among new buildings.

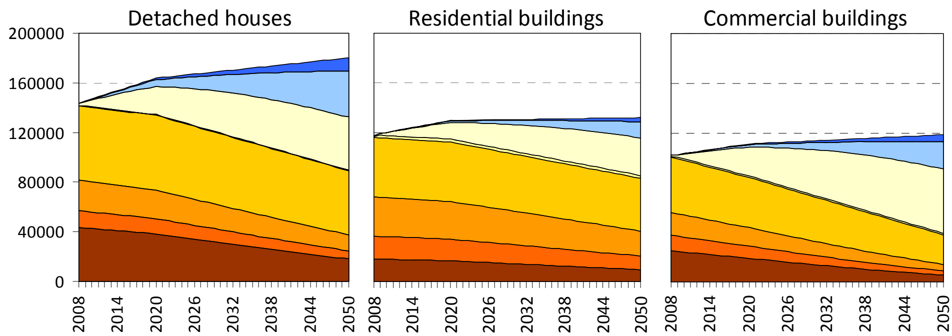


Figure B2. Delayed development (DD) has low energy buildings as the norm in new buildings by the 2030's but it takes time for the effect to show in the building stock.

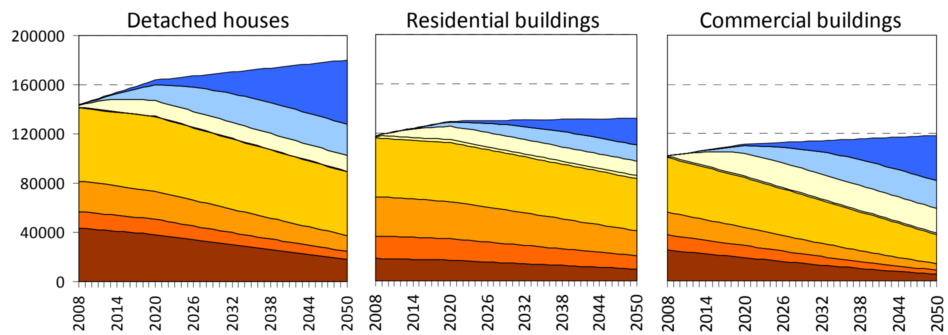


Figure B3. Rapid development (RD) has low energy buildings become the norm by the 2020's and passive buildings follow suit by the 2030's. This will allow the quick replacement of old stock with them.

Table B1. The effects of different energy savings measures implemented in the scenarios on the consumption of heating energy.

Scenario	Conservation measures		Heat consumption GWh/a		Savings potential GWh/a	
	Measures in new buildings	Measures in renovations	2020	2050	2020	2050
BAU	All new buildings are built according to 2003 standards.		**65000**	**56000**		
The effect of 2010 regulations*	Regulations are tightened 30 % in 2010.		**62000**	**47000**	**2700**	**8800**
Delayed development		The energy efficiency of the building shell is improved slightly during renovations that would be conducted anyway.			3100	3600
		The energy efficiency of HVAC equipment is improved slightly during renovations that would be conducted anyway.			4100	4700
	Low energy buildings will become the norm during the 2030's.				2800	10600
		Total for DD	**55000**	**37000**	**10000**	**18900**
Rapid development		The energy efficiency of the building shell is improved significantly during renovations that would be conducted anyway.			5500	6100
		The energy efficiency of HVAC equipment is improved significantly during renovations that would be conducted anyway.			7400	8300
	Low energy buildings will become the norm during by 2015, passive buildings during the 2030's.				3300	14800
		Total for RD	**49000**	**27000**	**16200**	**29200**

* Included in both RD and DD scenarios excluding the portion of buildings that would be built as low energy or passive buildings

Series title, number and report code of publication

VTT Research Notes 2581
VTT-TIED-2581

Author(s)
Juha Forsström, Pekka Lahti, Esa Pursiheimo, Miika Rämä, Jari Shemeikka, Kari Sipilä, Pekka Tuominen & Irmeli Wahlgren

Title

Measuring energy efficiency

Indicators and potentials in buildings, communities and energy systems

Abstract

The research project was launched to develop a general approach to measure energy efficiency. Furthermore, the research aimed to develop an approach which could be used to calculate the potential achieved by improved energy efficiency. Measuring energy efficiency and potentials are connected strictly to each other in the sectors of energy production, industry, buildings, communities, transportation and logistics. This report is a state-of-art description and a summary of the research findings from the energy, communities and buildings sector made by VTT.

Energy efficiency in energy chains was investigated in batch-surveys on the energy sector. Technical possibilities in energy chains have been evaluated for scenario calculation of energy saving potential in the future. Emissions of different energy production ways give the value for environmental impacts and further the impacts of making more effective energy chains.

Energy used in communities takes place in both buildings and infrastructure, during construction, use, maintenance, repair, renovation, demolition, and recycling as well as during transportation of people and goods. Energy efficiency of communities must be a composition of energy used during the life-cycle of several physical elements brought together for the community. Energy efficiency of communities can be defined as a ratio between an input of energy consumption or emissions, and an output of services, such as number of inhabitants and jobs or floor square metres.

Buildings have a high potential for energy efficiency improvements compared to other sectors of the economy. Various indicators serve different purposes and interests in the buildings sector serving from the user of the building to the regulator. Defining an universal indicator to cover all needs is not possible. Therefore an array of indicators is suggested – what indicator to use depends on the situation and the objectives of the analysis.

Energy flows and embodied energy with primary energy coefficients should be included in the evaluation. Large changes in system effects should be taken in with marginal primary energy coefficient and be analyzed with e.g. scenario analysis. Economic effects should be evaluated with e.g. economic modelling. Externalities and the rebound effect should also be considered.

ISBN
978-951-38-7707-1 (soft back ed.)
978-951-38-7708-8 (URL: http://www.vtt.fi/publications/index.jsp)

Series title and ISSN
VTT Tiedotteita – Research Notes
1235-0605 (soft back ed.)
1455-0865 (URL: http://www.vtt.fi/publications/index.jsp)

Project number

Date: April 2011
Language: English
Pages: 107 p. + app. 5 p.

Name of project: EPOEN
Commissioned by: Tekes, VTT

Keywords
Energy efficiency, production, building, community, chain, potential, indicator, meter

Publisher
VTT Technical Research Centre of Finland
P.O. Box 1000, FI-02044 VTT, Finland
Phone internat. +358 20 722 4520
Fax +358 20 722 4374

VTT CREATES BUSINESS FROM TECHNOLOGY

Technology and market foresight • Strategic research • Product and service development • IPR and licensing • Assessments, testing, inspection, certification • Technology and innovation management • Technology partnership

• • • VTT RESEARCH NOTES 2581 MEASURING ENERGY EFFICIENCY. INDICATORS AND POTENTIALS IN BUILDINGS, COMMUNITIES...

The research project was launched to develop a general approach to measure energy efficiency and the potential achieved by improved energy efficiency. They are connected strictly to each other in this report in the energy production and distribution, buildings and communities. The best way to save energy is in consumption, because it has an impact through the whole energy chain far to the primary energy sources.The building sector is a major consumer of energy with about 38% of the world's final energy being consumed in residential and commercial buildings. High saving potentials have been identified in buildings compared to the other sectors of the economy. Investment in energy efficient buildings is a cost-effective way to save energy. The design of CHP plants should be changed to mutch to supply district heating temperature for low energy buildings in the future. In Finnish town CHP plants the temperature reduction means that one could get about 10% extra power capacity. Communities have a relatively high potential for energy efficiency improvements. Potential seems to be highest in the operation phase of structures and transportation.

ISBN 978-951-38-7707-1 (soft back ed.)
ISSN 1235-0605 (soft back ed.)

ISBN 978-951-38-7708-8 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 1455-0865 (URL: http://www.vtt.fi/publications/index.jsp)