Measuring energy efficiency

Irmeli Wahlgren

VTT Technical Research Centre of Finland, Finland (irmeli.wahlgren@vtt.fi)

Abstract

Improving energy efficiency and combating climate change is one of the key targets in national and international policies. The research project "Measuring and potentials of energy efficiency (EPO)" was launched to develop a general approach to measure energy efficiency and to develop an approach which could be used to calculate the potential achieved by improved energy efficiency. The research covered the sectors of communities, buildings, transportation and logistics, industry and energy production. The research considered system boundaries and energy efficiency indicators for each sector as well as their combination. A Grande Case was carried out as a part of the project. The Grande Case combined indicators and methods of different sectors in one common study area. The results of the energy efficiency potential calculation show that it is possible to reduce primary energy consumption by 77 % and greenhouse gas emissions by 73 % of the most consuming and emissions causing alternative. If an area is located favorably in urban form and good solutions are made inside the area, the total primary energy consumption and greenhouse gas emissions can be decreased even by 80 %. This corresponds to energy and climate goals for 2050. The research verified that it is possible to combine metrics from different sectors in a single study. Emphasis should be put on reaching agreements concerning the standardization of energy efficiency calculation methods.

Key words: Energy efficiency. Energy efficiency measurement. Energy efficiency potentials.

Theme Area: Energy

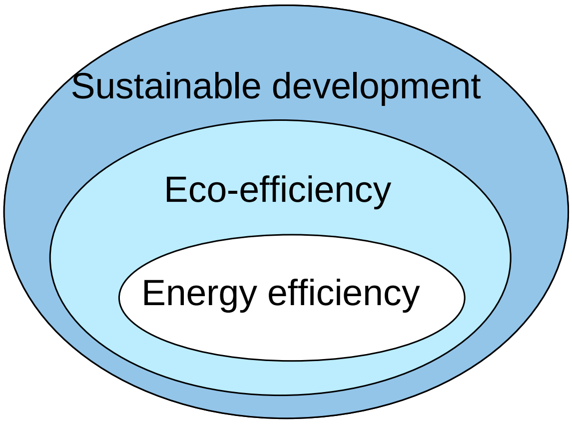
1 Introduction

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. 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 lauched in 2008 to facilitate development in this field (TUOMAALA et al., 2012, FORSSTRÖM et al., 2011). The research aimed to develop a general approach to measure energy efficiency and to develop an approach which could be used to calculate the potential achieved by improved energy efficiency. The research covered the sectors of communities, buildings, transportation and logistics, industry and energy production.

2 Energy efficiency, eco-efficiency and sustainability

Energy efficiency can be defined as a ratio between an output of performance, service, goods, or energy, and an input of energy. 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.

Figure 1 – Energy efficiency, eco-efficiency and sustainability (TUOMAALA et al., 2012, FORSSTRÖM et al., 2011).



Energy efficiency can be defined as a part of eco-efficiency. Eco-efficiency is ecological efficiency that measures use of natural resources and disadvantages in relation with results obtained. It can be defined as a part of sustainability. Sustainability covers ecological, economic and social 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.

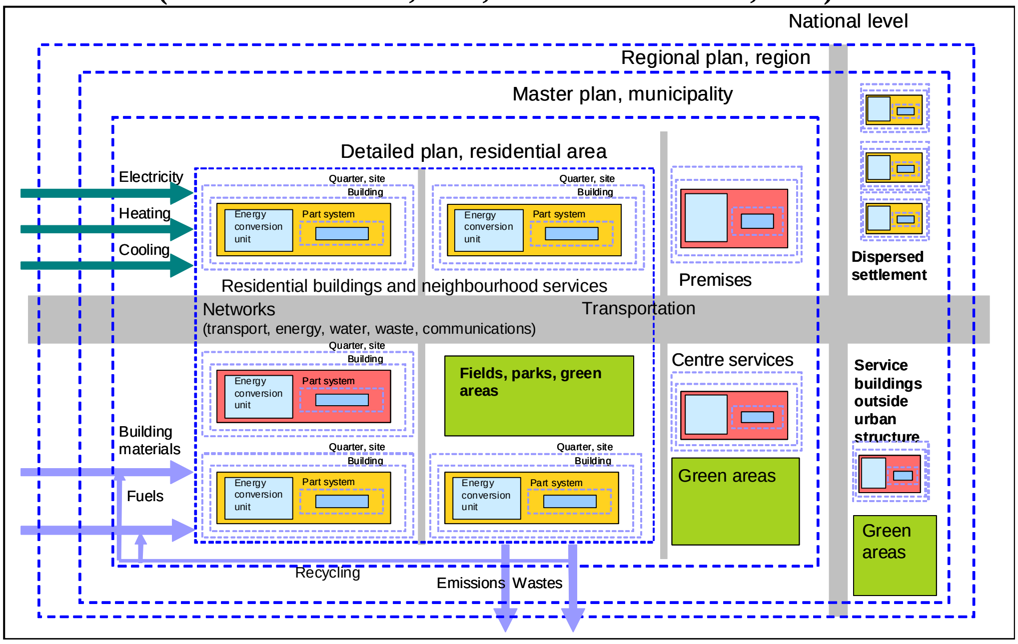
Together with energy efficiency (kWh/product or service unit) it is possible to measure amount of emissions or carbon foot print generated by production and operation (e.g.

CO_2-eq. kg/product or service unit). Together with energy efficiency, material efficiency may be measured. Assessment of the complex requires at least presence of the next factors: energy efficiency, material efficiency, relative amount of emissions and wastes, quality of environment and life as well as costs. (TUOMAALA et al., 2012, FORSSTRÖM et al., 2011)

3 System boudaries

When measuring energy efficiency it is essential to define appropriate system boundaries to avoid overlapping and part optimization. An example of system boundaries for measuring energy efficiency is given concerning communities (Figure 2).

Figure 2 – System boundaries for measuring energy efficiency of communities (TUOMAALA et al., 2012, FORSSTRÖM et al., 2011).



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. 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. System boundaries for master plan level, area of a municipality, part of it or several municipalities, include in addition the following factors: city center services; other premises (wide area); green and leisure areas (wide, serving the whole community); connection networks; transportation. Regional level system boundaries include in addition the following factors: scattered settlement; services outside communities; wide forests and green and leisure areas; regional and nationwide networks; transportation. (TUOMAALA et al., 2012, FORSSTRÖM et al., 2011)

4 Indicators of energy efficiency

Indicators of energy efficiency in five sectors were studied. Indicators and ways of their expression vary a lot. For example, 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 and operation of communities. Production of communities includes the whole production process of building materials needed in buildings, infrastructure and construction. Operation of communities includes use and maintenance of buildings and other structures as well as personal and goods transportation needed by functions of communities. 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.

Concrete indicators can be these ratios in communities sector: kWh/floor-sq. m, kWh/inhabitant, kWh/workplace, CO_2 eq. t/floor-sq. m, CO_2 eq. t/inhabitant, CO_2 eq. t/workplace. In buildings sector indicators can be: SEC (Specific Energy Consumption), kWh/sq. m, with possible adjustions for utilization rate. In logistics indicators can be: energy efficiency of delivery chain, MJ/ton-km. In industry: SEC, kWh/t. In energy production: process specific efficiencies, ratio of energy out to energy in, MWh/MWh.

Mathematical formulas for energy efficiency may be described in several alternative ways, for example energy efficiency of communities:

$$EEnC_{floor-sq.m} = \frac{kWh_{production} + kWh_{operation} + kWh_{transportation}}{floor - sq.m, a} \quad (1)$$

There are several energy efficiency indicators which consist of different parts and phases. Indicators complete each other. (TUOMAALA et al., 2012, FORSSTRÖM et al., 2011)

5 Energy efficiency potentials - Grande Case: Kalasatama

A Grande Case was carried out as a part of the research project. The Grande Case combined indicators and methods of different sectors in one common study area. The case study area was Kalasatama, a planned new residential and workplace area in City of Helsinki, having an excellent location in urban form (Figure 3). The Grande Case studied the real current plans of the area combined with virtual factors, such as location and energy production.

A basic alternative was developed for each sector, compatible with other sectors. Each sector (communities, buildings, energy systems, transportation, industry) formed their own calculation alternatives to study essential research issues. Communities sector studied energy efficiency of the complex of buildings, infrastructure and transportation. Research issues were impact of location, complementary building, and building density to energy efficiency. Energy systems sector studied performance of district heating and cooling and their alternative solutions for improving energy efficiency. Energy consumption of buildings was studied by three scenarios: business as usual building, passive houses and close to net zero (solar) buildings. Transportation sector studied energy efficiency of passenger traffic related to location alternatives of communities sector. Industry sector studied indicators of energy production and industry.

Figure 3 – Illustrations of the Master Plan of Kalasatama (City of Helsinki).

Primary energy consumption and greenhouse gas emissions of six alternatives were calculated, including: energy embodied in buildings and infrastructure (production of building materials), energy consumption of buildings (space heating, hot water, cooling, use of electricity, including energy transfer, distribution and production) and energy consumption of transportation (passenger traffic). In addition, energy production alternatives were studied.

The calculation alternatives were as follows:

1. *Dispersed settlement:* 18 000 inhabitants are located in periphery areas of the Helsinki region, instead of Kalasatama. Premises are located in Kalasatama, as planned.
2. *Loose structure:* 14 000 inhabitants are located in Kalasatama, and 4 000 inhabitants are located in car-zone of the Helsinki Metropolitan Area, instead of Kalasatama. Premises are located in Kalasatama, as planned.
3. *Kalasatama, basic alternative:* 18 000 inhabitants and 10 000 work places are located in Kalasatama, as planned. New buildings are built business as usual 2010 style.
4. *Kalasatama, passive houses:* Basic alternative with new buildings as passive house energy consumption.
5. *Kalasatama, close to net zero buildings:* Basic alternative with new buildings as close to net zero (solar) energy consumption.
6. *Kalasatama, urban factory:* Basic alternative with a bio refinery (Fischer-Tropsch plant) in the area.

Alternatives cause annually primary energy consumption 140 – 600 GWh and greenhouse gas emissions 26 000 – 96 000 CO_2-eq. tons. Energy consumption varies 105 – 301 kWh/sq. m and 5 – 22 MWh per number or inhabitants and workplaces, and greenhouse gas emissions 20 – 48 CO_2-eq. kg/sq. m and 0.9 – 3.4 CO_2-eq. tons per number or inhabitants and workplaces (Figures 4 and 5).

The dispersed settlement alternative causes most and the nearly net zero houses - alternative least energy consumption and greenhouse gas emissions. Difference between these alternatives is 4.3 folded as for primary energy consumption and 3.7 folded as for greenhouse gas emissions. This consideration can be seen as the maximum energy efficiency improvement potential in this calculation. Primary energy consumption of the least energy consuming alternative is only 23 % of the most consuming alternative, which means that energy efficiency improvement potential is 77 %. Decrease potential of greenhouse gas emissions is respectively 73 %.

Figure 4 – Grande Case Kalasatama – Annual primary energy consumption per number of inhabitans and workplaces (TUOMAALA et al., 2012).

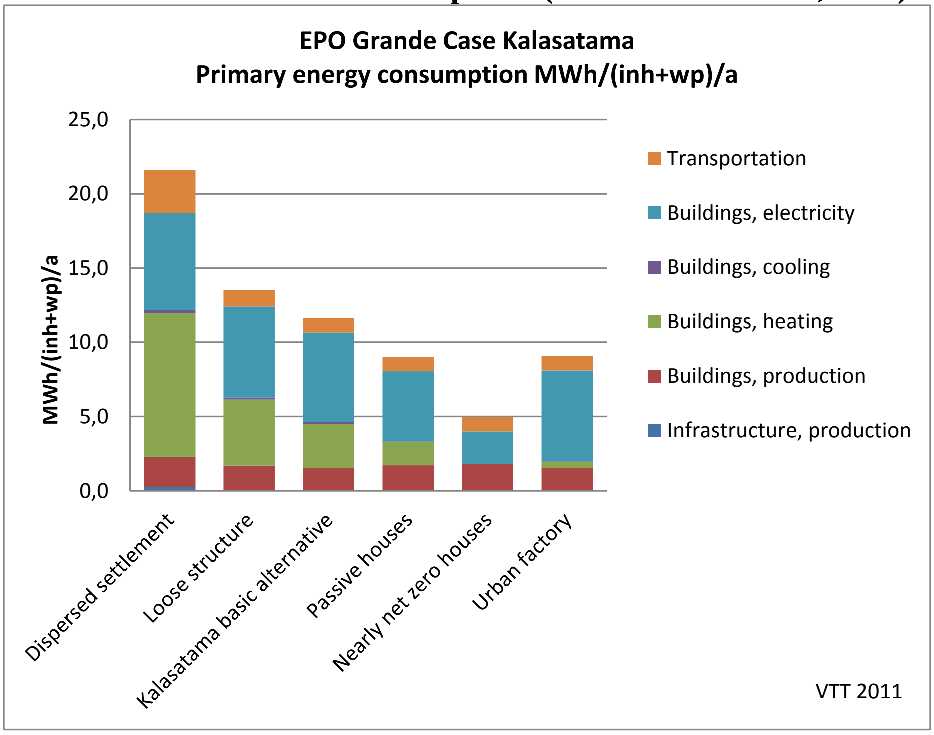
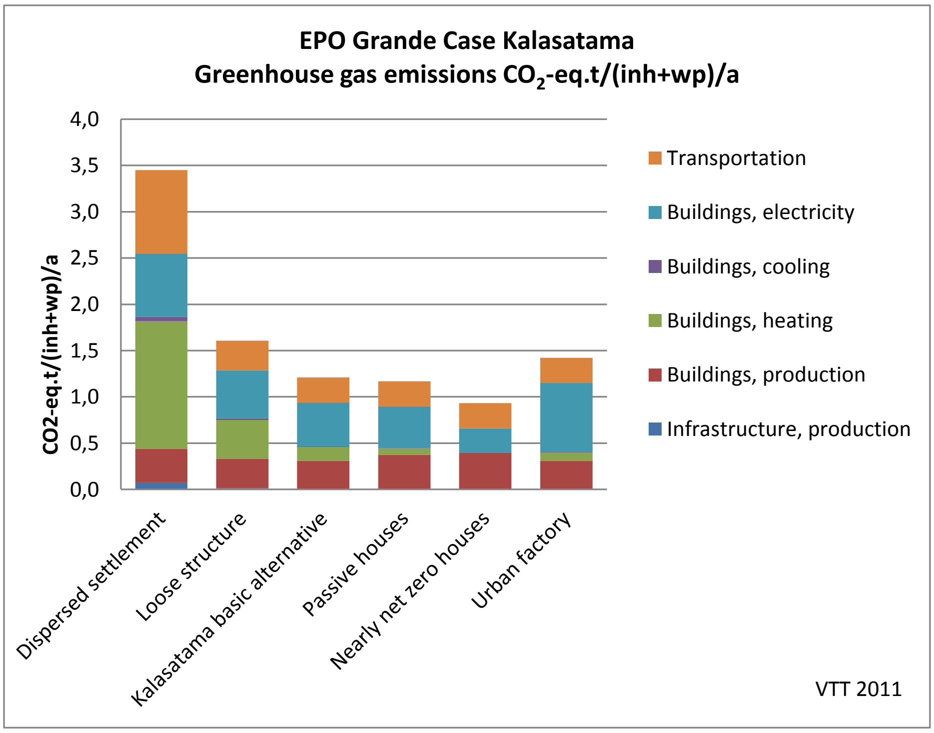


Figure 5 – Grande Case Kalasatama – Annual greenhouse gas emissions per number of inhabitans and workplaces (TUOMAALA et al., 2012)



Comparison of alternatives can be divided in impacts of location in urban form (transportation and charasteristics of housing) and solutions inside the area (energy efficiency of buildings and energy systems). As for urban form, dispersed settlement and loose structure alternatives are compared to Kalasatama basic alternative. Dispersed settlement alternative consumes 86 % more and loose structure alternative 16 % more primary energy than Kalasatama basic alternative. As for greenhouse gas emissions the relative differences are even greater: dispersed settelement alternative causes 183 % and loose structure alternative 32 % more greenhouse gas emissions than Kalasatama basic alternative.

As for solutions inside the area, Kalasatama basic alternative is compared to passive house, nearly net zero house and urban factory alternatives. Passive house alternative consumes primary energy 23 % less and nearly net zero house alternative 57 % less than Kalasatama basic alternative. Greenhouse gas emissions of passive house alternative are 4 % and emissions of nearly net zero house alternative 23 % smaller than emissions of Kalasatama basic alternative. Urban factory alternative causes 22 % less primary energy consumption and 17 % more greenhouse gas emissions than basic alternative. The reason for higher emissions is that in urban factory alternative district heating and cooling energy is produced by the FT plant, but electricity is obtained from average production.

Primary energy consumption is divided as follows: infrastructure 0.1 – 1.2 %, buildings 22 - 55 % and transportation 8 – 19 %. Greenhouse gas emissions are divided as follows: infrastructure 0.2 - 2.2 %, buildings 28 – 52 % and transportation 19 – 29 %.

Kalasatama has an excellent location in urban form. It has an efficient and minimum emissions causing transportation system. Energy consumption and greenhouse gas emissions from transportation are only 30 % compared to dispersed settlement and 85 % compared to loose structure. Kalasatama integrates and completes urban form. Kalasatama has a relatively high building density. Width of infrastructure is relatively small. Primary energy consumption and greenhouse gas emissions of buildings are less in Kalasatama basic alternative than in other urban structure alternatives, due to more effective building and favorable energy system.

Passive houses about halve the heating energy consumption and decrease consumption of electricity remarkably. Close to net zero energy buildings really gain zero energy consumption over a year in case of detached houses and at least halve net consumption of energy in case of other houses compared to passive houses.

Dense urban form enables an efficient district heating system with minor energy losses, even when passive houses will become more common. It enables also an efficient combined heat and electricity production system where heat and electricity can be produced with less fuels and emissions compared to separate energy production system.

Increasing the share of bio energy in energy production decreases greenhouse gas emissions of the plant, when bio energy is calculated to be CO_2 free. Impacts of bio energy production should be assessed from the whole production chain, including transportation. Energy production and use should be considered as a whole both in communities and in industry. Primary energy should be assessed based on real energy production system rather than in general primary energy coefficients.

Location in urban form affects essentially energy consumption and greenhouse emissions of transportation. Passenger mileage of private cars may be many folded in dispersed settlement areas compared to urban areas with good public transportation connections. Location in urban form is decisive for possibilities for walking and bicycling as well as public transportation.

Community level consideration combines measuring of energy efficiency of all the sectors. Favorable location of an area and energy efficient solutions inside the area make it possible to form an energy efficient community. Urban form choices may halve primary energy consumption of an area. Improving energy efficiency of buildings may further halve primary energy consumption of the area. If the area is located favourable and good solutions are made inside the area, the total primary energy consumption and greenhouse gas emissions can be decreased even by 80 %. This corresponds to energy and climate goals for 2050. Assessing energy efficiency of an area both location and solutions of buildings and energy systems should be taken into account. (TUOMAALA et al., 2012)

6 Discussion and conclusions

The Grande Case part of the research shows that Kalasatama is a very good area as regards improving energy efficiency and combating climate change, thus aspiring to overall sustainability. Kalasatama has an excellent location, an efficient and minimum energy consuming and minimum emissions causing transportation system, relatively high building density, and good possibilities for advanced energy systems.

The results of the Grande Case energy efficiency potential calculation show that it is possible to reduce primary energy consumption by 77 % and greenhouse gas emissions by 73 % of the most consuming and emissions causing alternative. Half of the total energy saving potential can be reached by location and structure and half by improving energy efficiency of buildings. Energy saving potential of buildings is 63 %, infrastructure 96 % and passenger traffic 67 %.

It is possible to consider energy efficiency of different sectors in one common area. Energy efficiency indicators developed in the first part of the research are well exploitable in an integrated energy efficiency consideration.

Based on the study it can be said that the methods being used to measure energy efficiency are still undeveloped, and much research is needed in this area. In practical work, emphasis should be put on reaching agreements concerning the standardisation of energy efficiency calculation methods.

On the basis of calculations it is possible to highlight the magnitude of different means for energy efficiency improvement. The most effective factors affecting energy efficiency are location in urban form, energy efficiency of buildings and efficiency of energy system. It seems to be possible to reach energy and climate targets.

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