Sustainable energy end use from a systems perspective

Agneta Persson
WSP Environmental
Sweden
agneta.persson@wspgroup.se

Keywords
energy efficiency, energy system, primary energy, CO_2-reduction

Abstract

What is most efficient from an integrated energy, environmental and cost perspective – measures in the individual building or in the supply system? Achieving the societal sustainable development goal requires a system's perspective including both energy demand and supply. But how should efficiency measures best be prioritised, taken economical and other limitations into account? How can the best possible use of resources be reached from a system's perspective?

Looking merely at delivered energy the Swedish building sector's energy end use appears to have decreased during the past 30 years. However, energy losses that earlier appeared in the buildings' individual heating systems have "moved" to energy transformation, and despite all energy-efficiency efforts the building sector's primary energy consumption has increased. To increase focus on sustainable development, ten Swedish major building construction and energy companies have performed a joint study to identify cost and resource-efficient measures to reduce the building sector's environmental impact. Resources have been calculated in primary energy consumption and CO_2 emissions.

This paper will present the results from the in-depth analysis of primary energy consumption and CO_2 emissions carried out in the project, with efficiency measures in the individual buildings, different energy supply systems and combinations of these. The analysis comprises new residential and office buildings, six different energy supply scenarios, a wide range of energy-efficiency measures, and costs based on a life cycle perspective. The study also included a sensitivity analysis of a number of studied parameters as well as a brief description of the project methodology.

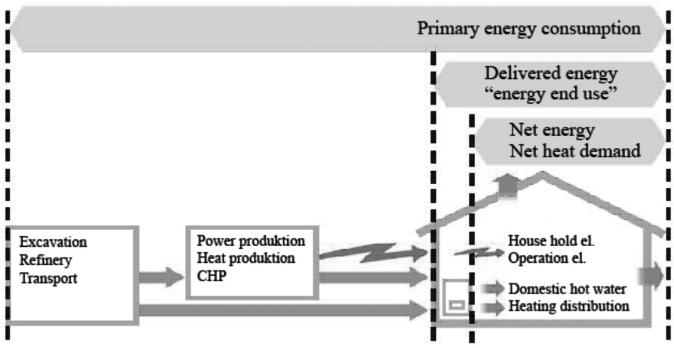

Figure 1: System boundaries for primary energy, delivered energy, and net energy respectively.

Introduction

Efficient energy end use in buildings and efficient energy supply systems are pre-requisites for achieving the societal goal of sustainable development. The question is in which order efficiency measures should be applied to reach optimal results taking economical as well as other constraints into account. To reach the best possible use of resources a system's perspective has to be applied. The relations between energy transformation and end use are complex and need to be more closely analysed.

Based on this question a joint study between the building industry and the energy industry has been carried out. The study includes new residential and office buildings, a number of efficiency measures, and six different supply scenarios.

Background

The Swedish building sector stands for the same share of total energy consumption as the EU average building sector, the well known 40 %. CO_2 emissions from the Swedish building sector are lower though. The Swedish building sector causes approximately 25 per cent of the national CO_2 emissions. Governmental agencies, the building construction industry, the energy industry and other important actors have put enormous efforts in energy efficiency during the past three decades. This has resulted in a 7 % decrease in relative energy end use in the building sector if you limit the analysis to delivered energy. However, if you adopt a system's perspective including all losses from exploiting the energy source and transports, energy transformation and distribution, the result is totally different. Such an analysis shows that the building sector's relative energy consumption (kWh/m^2 per year) despite all energy efficiency efforts during the past 30 years has increased with 11 per cent.

To contribute to a more efficient and rapid development, the Swedish building sector and energy sector has conducted a joint study aiming at identifying the most cost- and resource-efficient measures to reduce the built environment's environmental impact, and to achieve an energy supply system with the least possible environmental impact. In this study primary energy factors and primary CO_2 emission factors have been calculated and used as indicators of resource need and environmental impact.

- Primary energy and CO_2 emission factors are calculated from a life cycle analysis (LCA) perspective, including the whole chain from excavation through transformation and distribution, and losses in the individual building to actual energy end use.
- Primary energy factors and the primary CO_2 emission factors are given in kWh per m^2 heated area and kg CO_2 per m^2 heated area respectively.
- The analysis comprises one recently erected residential multi-family building and one new office building. For each of the two houses a number of efficiency measures have been simulated.

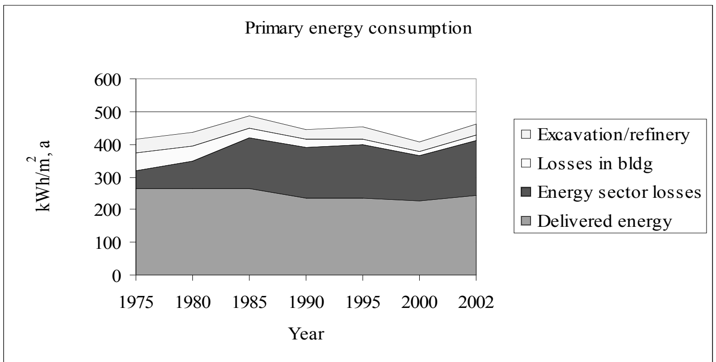

Figure 2: The Swedish building sector's energy end use from 1975 to 2002. The figure shows delivered energy and corresponding losses. (Source: Persson et al, Swedish Energy Agency, 2005.)

- Environmental impact and cost-efficiency have also been calculated for each efficiency measure in combination with sex different energy supply scenarios.
- Life cycle cost calculations (LCC) from the end user's perspective have been used for cost efficiency calculations.
- In addition a comparison of the studied buildings has been made with four well-known Swedish low-energy buildings.

Results

The study shows measures and combinations of measures leading to both lower LCC costs, decreased primary energy consumption and decreased environmental impact. It also shows measures and combinations of measures which are cost efficient but lead to higher primary energy consumption and increased environmental impact. And it shows measures which neither are cost efficient nor lead to decreased environmental impact. However, it should be stressed that this study merely includes two real buildings and six different supply scenarios. Furthermore the study uses a set of specific assumed factors regarding resource allocation, climate impact and costs. A choice of other buildings, supply cases, costs or resource factors may lead to different results. To be able to draw general conclusions further studies regarding alternative costs and environmental impact factors are needed.

Some of the interesting conclusions from the study are:

- Environmental impact and resource need may vary by a factor two in a specific building with application of different measures, although the delivered energy only varies slightly.
- In combination with combined heat and power production (CHP) traditional exhaust air ventilation systems without heat recovery may be almost as resource efficient as balanced ventilation (exhaust and supply air system) with heat recovery, ESX.
- Primary energy consumption of heat pump solutions with an average coefficient of performance (COP) of 2.5 exceed the primary energy consumption of most solutions with exhaust air ventilation systems without heat recovery as well as systems with ESX ventilation (e.g. exhaust air heat pumps and ground heat pumps). To achieve lower primary CO_2 emissions the heat pump's COP has to exceed 2.5.
- Well-known examples of energy-efficient buildings such as Lindås Park (passive house), the Jöns Ols residential building in Lund, and the "Astronomihuset" office building in Lund show to be relatively normal regarding primary resource use (primary energy as well as primary CO_2 emission).

The analysis carried out in the study shows that primarily four measures or combination of measures are cost efficient (LCC) and at the same time leading to lower environmental impact compared to the two base case buildings used in the study. These four categories are (in cost-efficiency order):

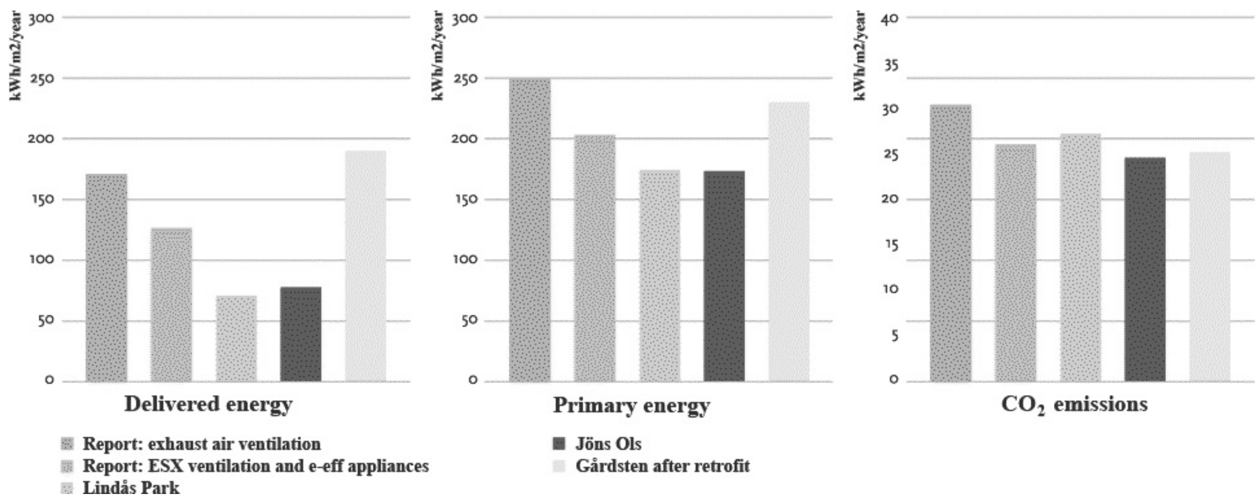

Figure 3: Comparison on delivered energy, primary energy consumption and primary CO_2 emissions between the studied residential building, Lindås Park passive house, the Jöns Ols residential building (Lund) and an existing renovated residential multi-family building in Gothenburg.

1. DECREASED USE OF ELECTRICITY

The most significant decrease in terms of environmental impact and at the same time being cost efficient is achieved with measures reducing electrical end use. Typical measures in residential buildings are e.g. avoiding electrical heating, installing high performance appliances or CFLs. Even when taking into account that some of these measures may lead to an increased heat demand, these measures significantly contribute to reduced primary energy consumption and CO_2 emissions, and at the same time being very cost efficient.

In the office building case measures reducing electrical end use often have double effect through reduced need of ventilation and/or cooling when reducing internal heat loads from appliances and lighting. All analysed measures reducing electrical demand are cost efficient and lead to reduced environmental impact in terms of reduced primary energy consumption and CO_2 emissions.

2. USE CHP PRODUCED DISTRICT HEATING

The second most cost-efficient way to reduce environmental impact is to choose CHP produced district heating. Here biomass based CHP is more cost-efficient than CHP based on natural gas. However, two reservations have to be made here. Firstly, CHP production costs used in the study are not necessarily corresponding to the facility owner's or end user's district heating cost. However, the end user's room for negotiation with the district heating company may increase with this knowledge. Secondly, the individual end user can not decide on the local district heating company's choice regarding heat production or energy sources.

3. REDUCED ENERGY NEED FOR HEATING

The third most cost-efficient category of measures reducing primary energy consumption and primary CO_2 emissions is measures reducing heating energy need. In the study high-performance windows and increased insulation have been analysed. High performance windows have merely a slight incremental investment and are very cost efficient from a LCC perspective.

4. REDUCED ENERGY NEED FOR HEATING AT A MINOR INCREASE OF ELECTRICITY END USE

The fourth category being both LCC cost efficient and reducing environmental impact includes measures which significantly reduce energy need for heating at a minor increase of electricity end use, e.g. installation of supply and balanced ventilation with heat recovery (ESX ventilation). This measure leads to a significantly larger reduction of primary energy consumption and CO_2 emissions than measures mentioned in category 3 "Reduced energy need for heating" above, and would have been higher ranked should investments be merely slightly lower than the costs used in the study[1].

How much lower must the energy end use for heating be to balance the use of incremental kWh electricity?

The necessary reduction of heating energy demand to balance the environmental impact of the use of incremental kWh electricity depends on what energy supply system the comparison is based on. As already mentioned, in this study primary energy and CO_2 emission factors have been calculated including the whole chain from excavation of the energy source to actual end use. 80 per cent of all residential and office buildings in Sweden are supplied with district heating. The Swedish District Heating Association's forecast on average mix of energy sources for 2010 and European marginal electricity production has been used as baseline in this study. With this supply system scenario a reduction of 3 kWh heat is needed to balance each added kWh in terms of electricity primary energy consumption. The corresponding number for primary CO_2 emissions is 5.6. The 2010 district heating forecast includes a certain share of CHP. Should

1. A large number of varieties exist when it comes to ESX ventilation. A sensitivity analysis based on a number of real case alternative costs has been carried out in the study. The sensitivity analysis shows a high level of LCC cost efficiency for cases with only slightly lower investment costs than the base case investment used in the study.

the CHP produced district heating increase compared to the 2010 forecast, an even larger reduction of heat demand is necessary to balance each kWh increase in electricity demand.

In the short term perspective it is reasonable to assume that it is environmentally sound to invest in measures reducing heat demand in accordance with the ratios 3:1 between heat and electricity demand when discussing primary energy consumption, and 5.6:1 when it comes to primary CO_2 emissions. In a longer term perspective a new forecast of the district heating mix has to be made. Given the current Swedish development it is probable that such a forecast would include a larger share of CHP.

The studied buildings

The base case for the residential building is a multi-family building with 15 apartments. The building is situated in Stockholm and the families moved in 2004. The building has a mechanical exhaust air ventilation system, good insulation performance, and A-labelled appliances. The residential building's total yearly energy demand is 170 kWh/m². The residential building simulations have been made for a number of measures and combination of measures: e.g. balanced ventilation with heat recovery, heat pump, improved insulation standard, high performance (A+ and A++) appliances, and replacing electrical comfort heating in bathroom floors with district heating.

The office building used in the study is based on operation statistics for a number of new office buildings with high performance insulation and windows, and sun screens in south and west to avoid cooling demand. The base case includes balanced mechanical ventilation with heat recovery with a good COP. The total delivered energy for the office building is 182 kWh/m². Measures and combinations of measures simulated for the office building include "free cooling" (passive cooling), energy efficient lighting, day lighting solutions and division in building control system zones, high performance ventilation systems, improved sun screens, air born cooling, variable air volume ventilation systems, and decentralised cooling with a higher COP.

The studied supply systems

Since 80 per cent of all multi-family residential and office buildings in Sweden are supplied with district heating it was natural to choose several supply system scenarios based on district heating. These are the following: district heating 2010 forecast, biomass based medium sized district heating system, district heating based on biomass CHP, and district heating based on natural gas CHP. Two local heat supply system scenarios where also used, these where ground heat pump and local biomass combustion. In the analysis electrical end use has been seen from an average European and a future marginal (natural gas combination) supply perspective.

Sustainable development requires a system's perspective

The study clearly shows that a system's perspective including both energy supply and energy demand is necessary to achieve a sustainable development. The study highlights a number of measures and combination of measures which are cost efficient and at the same time lead to reduced resource need and environmental impact. Naturally there are several other measures apart from those analysed in this study, both on the supply and the demand side, which may lead to the same or even larger primary energy and CO_2 emission reductions. However, in order not to make the analysis too complex limits in numbers of efficiency measures and supply system scenarios had to be made. A second phase of the project is about to start. This phase will include more measures and supply system scenarios, and probably also more on existing buildings.

The general conclusion from the study is that to reach a sustainable energy system, it is not sufficient to focus on delivered energy only. There has to be a shift of focus towards CO_2 emissions and primary energy consumption, over the whole chain from excavation of energy sources to end use.

Acknowledgements

This paper summarizes a study which was financed by the Development Fund of the Swedish Construction Industry, the Swedish District Heating Association, E.ON Värme, Fortum Värme, Göteborg Energi, JM, NCC Teknik, Skanska Sweden, Tekniska Verken i Linköping, and Veidekke Bostad.

References

Persson A: "Energianvändning och -försörjning för byggnader ur ett systemperspektiv - Ett samverkansprojekt mellan bygg- och energibranschen" ("Energy demand and supply for buildings in a system's perspective", in Swedish), The Development Fund of the Swedish Construction Industry and the Swedish District Heating Association, 2006.

Persson A et al: "Allt eller inget – Systemgränser för byggnaders uppvärmning", ("All or nothing – System boundaries for building heating", in Swedish), Swedish Energy Agency, 2005.

Abbreviations

CFL	Compact Fluorescent Lamp
CHP	Combined heat and power production
COP	Coefficient of performance
ESX	Balanced ventilation (exhaust and supply air system) with heat recovery
LCA	Life cycle analysis
LCC	Life cycle cost calculation