ENVIRONMENTAL ASSESSMENT OF ENERGY SYSTEMS FOR HEATING IN DWELLINGS

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Abstract – So far economical aspects have been highlighted when choosing heating system in dwellings. However, with today's increased environmental awareness also requirements on environmental aspects are important. It is not enough to have a low energy demand; it must also be supplied by a source with low environmental impact. It is, however, a big difference between kWh and kWh since the environmental impact depends on many factors such as, type of used heating system, effectiveness of the system and energy source. The large number of influencing factors makes it difficult to estimate and assess the environmental impact and there is a lack of methods and tools for an easy comparison.

Within the research programme EFFEKTIV a method has been defined for environmental assessment of heating systems and an Internet tool for fast estimations has been created. The tool intends to be a support for environmental advice in choices between different heating systems and thereby increase the market for systems that are using renewable energy sources, such as sun, wind or bio fuels. The method is based on assessment of environmental impact from emissions. All emissions during the energy source's complete life cycle are considered "from cradle to grave". The emissions are divided into categories dependent on their impact on global warming, acidification, photochemical ozone formation, eutrophication, and fine particles.

The free-to-use Internet tool EFFem gives a fast, transparent and objective overview of the environmental effects for different heating systems, but negative environmental aspects from nuclear power will not be reflected.

1. INTRODUCTION

The building stock in Europe is today responsible for about 40 % of the total energy use and thereby also for the corresponding emissions to our environment. It is therefore the sector that uses most energy, even more than the traffic sector. During the last years has the environmental impact therefore become important at assessments of building's energy use, together with influences from economical factors and users aspects such as comfort and reliability. However, good and easy-to-use tools that can calculate the environmental impact for assessments when choosing between heating systems and energy efficient measures are still missing. These tools are requested by energy counsellors for environmental advises to private house keepers, by real estate companies that need the information for environmental planning of large residential areas and by energy companies that need to do an environmental declaration to private customers.

In recent years about twenty methods to assess environmental aspects of buildings have been developed. Examples are "One number says it all" (Croes, 2000), BREEAM (Yates et al., 1998) and Green Building assessment Tool (Cole and Larsson, 1999).

These methods particularly concern environmental aspects in suburb or city locations, the garbage lifecycle etc. Several of them also include aspects of environmental impact of energy used for the whole lifecycle of the building; construction, operation and demolition. However, the aspects are considered in ways that are not directly useful as required for the requested need of easy-to-use tool. The impact of the energy used for the operation of the building is often not considered in detail and there are no options to assess between different energy sources.

Therefore the main objective with this project is to develop a tool for environmental assessment of a building's energy use. Partly by developing a method and to harmonize it for acceptance, and partly by developing an Internet program with calculations according to the method.

2. THE METHOD

2.1 Environmental impact from a building

The environmental impact from a building will continue during the complete lifecycle of the building and can be divided into three main phases; *construction*, *operation* and *demolition.*

During the *construction phase* the environmental impact arise from manufacturing of building materials and components, transportation of materials and components, and construction. Thereby an environmental impact arise by use of material resources, by emissions from energy use at the construction and transportation and by care taking of waste from remaining material.

During the *operation phase* there will be an environmental impact at maintenance and renovations of the building, but the largest impact is generated by energy use for the daily operation.

During the *demolition phase* environmental impact arise by energy use at the demolition, but also at sorting and transportation of the waste material for care taking i.e. scrapping, combustion or re-use.

Some detailed lifecycle investigations have been made during the last years; for typical and low energy family houses in Norway (Németh Whinter, 1998), for typical three storey office buildings in Vancouver and Toronto, Canada (Cole, 1996), for typical multi-family houses in Sweden (Adalberth, 1999), for low-energy family houses in Sweden (Adalberth, 2000), for a typical single family house at different places in USA (Van Geem et al., 2001) and for typical residential buildings, schools and offices in Sweden (Ståhl, 2002). These investigations have showed that the energy use for operation counts for the major part of the total lifecycle energy use (between 80 and 95%). Less than 20% is used for manufacturing of building materials, transportation of materials, construction, maintenance and demolition. These conditions might of course be totally different in other climates and in other building cultures, for example for south European conditions.

Efforts to decrease the environmental impact from energy used in the operation phase will therefore have high effect and the main part of the energy related impact from a building can be assessed by calculation with a relatively small amount of input data. The new method is, therefore, based on operation energy use.

However, with measures to decrease the energy use in the operation phase, the energy use for construction, maintenance and demolition will become more important. For example, a 50% reduction of the operation energy use will give a decrease of the operation energy part to 70% of the total lifecycle energy for the investigated offices in Canada (Cole, 1996). Nemeth Whinter, 1998, shows that a house with super insulation and a heat pump can reduce the operation energy part to 58% of the total lifecycle energy. It will be important to include the building's total lifecycle in the future (as in several of the above-mentioned methods), when the operation energy use will –hopefully- decrease.

2.2 Operation energy use

A building's energy need is dependent on several factors such as the outdoor climate where the building is situated, requirements on indoor comfort (climate, ventilation etc), the building's construction (the building's climate shield, e.g. envelope tightness, quarter orientation and material) and the activity in the building (heat generation from people and working machines).

The energy demand is supplied by one or several technical installations that will affect the environment. The degree of impact is dependent on the technical systems' effectiveness and which energy sources are used.

The new method is developed with energy use as input to the assessment. For new buildings the energy use can be calculated with one of today's existing simulation programs and for existing buildings with reading of energy bills.

2.3 Environmental impact of the energy sources

The environmental impact from the energy source begins long before the energy is used in the building. It begins already at extraction, production and transportation of the energy source to the building. Further environmental impact will arise at transformation (e.g. combustion) of the energy source either in the building directly or in a central energy unit that supplies the heating/cooling demand in several buildings. The impact will also arise at construction of means of transports and/or energy plants. For example from the time when oil is extracted until heat has been distributed to the building and all waste products have been taken care of. To get an overview of the outdoor environmental impact, studies have been made on life cycle inventories and life cycle assessments (LCI/LCA) of different energy sources.

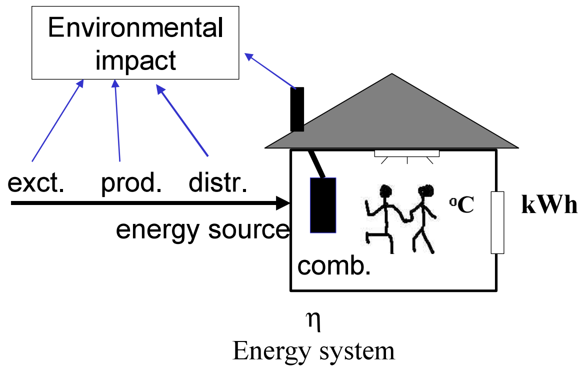

Figure 1: A building's environmental impact is dependent on the building's energy need, the effectiveness of supplying energy system and the energy source's life cycle.

3. LIFE CYCLE OF THE ENERGY SOURCES

A life cycle assessment, LCA, describes a products total environmental impact from "the cradle to the grave". Life cycle assessments are used for comparison and not to descriptions in absolute terms. A LCA can be divided into four phases: *Objective and scope*, *inventory analysis, environmental impact description, and interpretation.*

3.1 Objective and scope

The detailed design of an LCA is adapted individually after the analysis purpose, which questions shall be answered and what the analysis should be used for. All demarcation and assumption shall be stated and a functional unit shall be defined. The system boundaries shall be well defined.

All use of energy will in some way cause impact on our environment at local, regional and global scales. The environmental impact can be divided into three main loads:

- Emissions to air, soil and water. The emissions can be in gas, fluid or solid phase.
- Use of natural resources, i.e. material, energy or land.
- Deposit of waste that are not possible to re-use.

So far both environmental impact due to emissions to air and use of natural resources have been studied in the project (Wahlström et al., 2001 and Wahlström and Olsson-Johnsson, 2002). Emissions to air accounts for the large majority of the material flow from energy production based on fossil fuels or renewable energy sources, and thereby also for several of the serious environmental impacts. The built up Internet tool has only considered emissions to air, see Chapter 4.

The functional unit for the assessment's result is one kilowatt-hour (kWh) net energy, heat or electricity, used in the building.

The system boundary is chosen as the energy source's complete life cycle. The environmental impact of the greenhouse effect for extraction, production and transportation of wood is, for example, over 40% of the total life cycle emissions from wood combustion (Uppenberg et al., 1999) and therefore consideration of the complete life cycle is important.

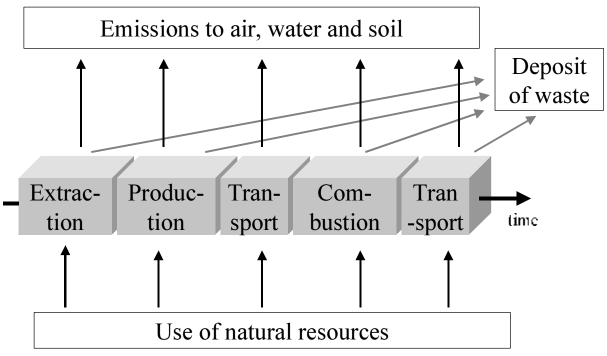

Figure 2: The environmental impact during the energy source's lifecycle.

3.2 *Inventory analysis*

The inventory analysis is objective and based on facts. It quantifies all flows of emissions to air, soil and water, all use of natural resources and all deposit of waste during the complete life cycle of the examined product. It is performed in three steps; first a flow chart is made for the chosen system boundary, thereafter flow data are collected and finally calculations are made.

A database with life cycle inventories for several different energy sources has been created (Wahlström et al., 2001 and Wahlström and Olsson-Johnsson, 2002). The database consists of emissions to air by the substances CO_2, SO_x, NO_x, CH_4, CO, N_2O, NmVOC, NH_3, HFC:s and particles and is for general life cycle inventories. This means that they are based on the average from several units for the heating systems or they are representative for a certain type of heating systems. The collected life cycle inventories are representative for normally used technical systems today. Newest possible technique would give a lower environmental impact while old technique will give a higher environmental impact.

3.3 *Environmental impact description*

In the description of the environmental impact the information from the inventory analysis is summarized to something more easy to survey. At the same time the potential environmental impact is described in a relevant way. The inventory data is transformed to contribution to the environmental impact in three main steps:

- classification,
- characterisation,
- weighting.

At the *classification* the emissions to air are grouped into categories due to their impact on significant environmental effects. The different environmental impact categories are in the new method green house gases, acidification gases, top dressing gases, ground-level ozone gases and fine particles. Since energy use does not normally count for high emissions of ozone depletion gases they are not considered here. The classification is based on scientific facts.

In the *characterisation* the contributions to different impacts are weighted together within each category through multiplication with characterization factors. Thereafter the contributions are summarized to one characterization indicator. The characterization can be based on scientific facts or subjective valuations.

In the new method characterization is made in accordance with recommendations in the Environmental Performance Declarations (Swedish Environmental Council, 2000) for the environmental effects; global warming, acidification, photochemical ozone formation and eutrophication. However, resent studies of the environmental impact of fine particles, have showed that fine particles penetrates directly into the lungs, causing allergies, cardiovascular and respiratory diseases and cancer and must therefore also be considered (Tiuri, 1998).

The characterisation step is resulting in several characterization indicators that still are difficult to survey at an environmental assessment between two alternatives. Therefore a few assessment methods have been developed, that are *weighting* the different characterization indicators into one or just a few index. (For example EPS (Steen, 1999 and Ryding et al., 1998) and Eco-indicator 99 (Goedkopp och Spriensma, 2000). The weighting is based on subjective valuations. Most weighting methods try to catch and describe how society aspects to assess different environmental categories.

The new method is not considering the weighting step and is instead accounting for the environmental effects described above separately. The valuation is thereby more or less based on science.

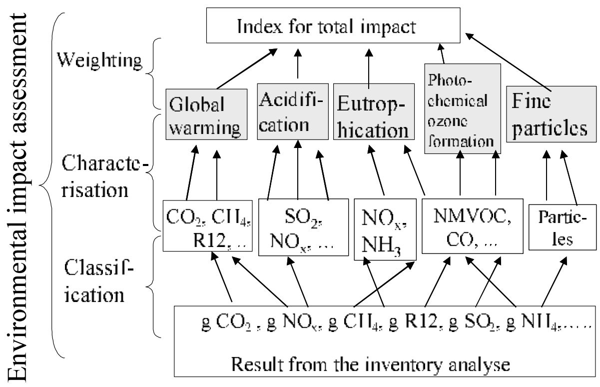

Figure 3 Environmental assessment with lifecycle analysis.

3.4 Interpretation

In this phase the result is interpreted for comparison between different alternatives. The results from the inventory analysis, the characterisation and the weighting are used in parallel to assess differences and uncertainties. Usually several weighting methods are used when the weighting step is necessary for an assessment. This phase is not considered in the new method and is left for the user to evaluate. The new method is only serving the user with the result from the characterisation step.

4. SYSTEM BOUNDARIES

For buildings that are heated by electricity or district heating the environmental assessment is directly influenced by the systems boundary conditions. District heating and electricity are often produced centrally in different production units that are connected into the same distribution net. Examples of production units are wind power, nuclear power, a coal thermal power plant or a bio fuel heating-plant. Different units will be included into the environmental assessment depending on how the system boundary is defined. The definition is different depending on what the environmental assessment should be used for and therefore it is often not possible to compare different environmental assessments directly.

4.1 Electricity

Electricity is distributed through a net that often is directly connected with distribution nets all over Europe and also to other parts of the world. Since global warming is a global impact it doesn't matter if the impact is reduced locally or somewhere else.

For example, electricity will be very beneficial to use if only Norwegian power, which mainly consists of waterpower, is considered in the assessment. Due to the market situation a reduction in electricity use could cause Norwegian electricity to be used instead of coal power produced in another European country and when it would be beneficial to reduce the electricity consumption also in Norway. This means that the environmental assessment for electricity is complicated since the total market situation should be taken into account and this is reflected by the choice of system boundary.

This has been described by Werner (Werner et al., 2001) that analyse how the delivery of additional heat for heating a building will affect the total change of carbon dioxide emissions due to the market situation (Figure 4).

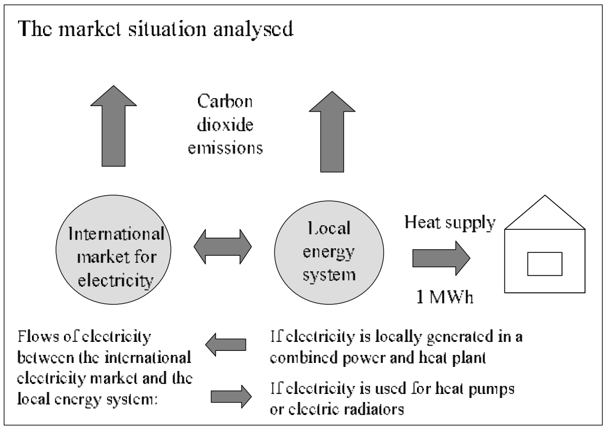

Figure 4: The market situation analysed for estimating the net emissions of carbon dioxide from various technical options in the local energy system (Werner et al., 200).

For electricity there are three common ways to define the system boundary for the mix of production units:

- average mix(European/ national/regional),
- marginal mix,
- environmentally labelled mix.

An *average mix* consists of the percentage composition of production units within the system boundary e.g. in Europe, the nation or the region. This definition will describe the actual contribution from the building to the environmental impact.

A *marginal mix* consists of the production unit that is used on the last place. A reduction in the electricity consumption will lead to that the production from this unit can be reduced. This definition describes how the environmental impact will decrease with electricity saving measures.

An *environmentally labelled mix* consists of specified production units with specified low environmental impact.

4.2 District heating

The situation for district heating is simpler than for electricity. Usually the district heating nets are separated from each other and with clear system boundaries. Their mix of production units can be very different within different nets and thereby also their environmental impact. It can here be very misleading to do the environmental assessment based on a national or European mix of production units. To do a proper environmental assessment data is needed about production units for the specific district heating net considered.

4.3 Allocation

Another demarcation at an environmental assessment is when the environmental impact should be divided between more than one product. This is the situation at combined power and heating production where the emissions are divided between heat and electricity. Such a division is called allocation and for combined power and heating production there are two common ways for allocation:

- the energy method,
- the alternative production method.

In the *energy method* each produced kilowatt-hour will have the same environmental impact irrespective of whether the produced kilowatt-hour is heat or electricity.

To use fuel for combined power and heating production instead of producing electricity in a power plant and heat in a heating plant will totally give a better way of using the fuel. In *the alternative production method* (Nilsson and Strömberg, 2000) this is considered and the emissions are divided based on the gain by using fuel better in combined power and heating production. The emissions are divided between the produced heat and electricity with the proportions of fuel need for separate electricity and heat production.

Another advantage is to use waste heat that otherwise will be lost, for example sewage from a municipality, or hot streams from industry. The emissions from these heating sources are often allocated to the main product in the industry, which gives zero emissions for waste heat. Here aspects such as availability, alternative use and if it is possible to produce the industrial product without any waste heat must be considered.

Sources such as high quality heat from an industry that can be used to produce electricity are not considered as waste heat. These energy sources should be regarded as products from the industry and the lifecycle inventory should be based on all emissions and products from the industry.

5. THE INTERNET TOOL

The method for assessment of environmental effects from emissions has been programmed into a free-to-use Internet data program (EFFem, 2002), where the environmental effects from different heating systems can be calculated. The tool intends to be a support for facilitating environmental assessments in choice of different heating systems and thereby increase the market for systems that are using renewable energy sources, as sun, wind or bio fuels.

5.1 Comparison of different heating systems

The heating systems that can be studied in the Internet program are heat production from boilers combusted with oil, natural gas, wood and pellets, heat production with a heat pump and heat distribution with district heating or direct electricity.

The comparison can be made in two ways. The first option is to compare the system that should be assessed (e.g. data from the heating system in the own house) with the other heating systems, which data are representative for normally used technical systems today. The other option is to compare two specified choices of heating systems.

5.2 Boundary conditions

The program is built so that both assumptions and boundary conditions are transparent and easy to change. This means that the user should be able to find references to the used input data and descriptions on assumptions the stepwise calculations that are the base for the results. This is important in order to make it possible for the user to do the evaluation based on the judgments that are relevant for the specific assessment and change default values to relevant values.

5.3 Default values

The input data to the Internet program is the energy needed for the building during one year expressed in kWh. Since the program does not calculate the energy use the user must have enough information to be able to specify it.

EFFem is today an Internet program with public accessibility, which means that the users have very different knowledge about input data. Therefore, the program is built up with default values for efficiencies of different heating systems and for emissions of the different energy sources. These data are collected from different life cycle inventories and are representative for normally used technical systems used in domestic houses, district heating and power generation today.

To make an assessment for newest possible technique or for old technique will require some changes in the default values.

5.4 System boundary for electricity and district heating

Since the assessment of heating system based on use of electricity or district heating is directly influenced by the system boundary, and that the system boundary may be different dependent on what the environmental assessment should be used for, the program have several options for choosing system boundary.

Use of electricity may for example be chosen as average mix from the Swedish production, by marginal mix or by environmentally labeled mix of production units.

Both electricity and district heating have their own options, which means that the user may specify the percentage mixture of different production units. Here different national or regional mixtures of district heating or electricity can be specified.

The Internet program's data base will during the next year be further extended with data from the members in the Swedish District Heating Association. The purpose is that the assessment should be possible to make directly with data that are specific for the local district heating system in consideration.

For combined power and heating production the program is allocating the emissions according to the *alternative production* method. All emissions from waste heat are allocated to the industrial product, which gives zero emissions for waste heat.

Bio fuel and other organic energy sources are considered as parts in the natural carbon dioxide circulation and their carbon dioxide emissions at combustion are therefore considered as zero.

5.5 Results

The results of the calculations are shown as environmental effects and not as one weighted index. This is meant to give a plain basis for the user to do the final assessment. For example a heating system that has a low impact on global warming may at the same time have a high impact on acidification. An assessment of whether impact on global warming is worse or better than acidification is a subjective evaluation and is dependent on what the environmental assessment should be used for.

The emissions to air have been categorized depending on their impact on global warming, acidification, photochemical ozone formation, eutrophication and emission of fine particles.

6. DISCUSSIONS

6.1 Use of natural resources and deposit of waste

The Internet tool has only considered emissions to air which accounts for several of the serious environmental effects. However, use of natural resources and deposit of waste, which both also are important aspects, are not considered.

To preserve nature's sustainability, the natural resource depletion must be limited. It is therefore important to choose energy sources that have short-term effect on the resource availability. It is also important to avoid energy sources with environmental impact such as radiation and radioactive waste. Other aspects such as advantages to use waste heat from a nearby factory or to produce heat from combustion of waste instead of deposit are also important to consider when choosing energy sources. The user himself must add these aspects to the assessment.

As mentioned; use of natural resources will not be directly considered in the Internet tool even though its consideration is important. However, the lower priority of non-renewable energy sources, except nuclear power, are already reflected in the assessment of global warming since they have high carbon dioxide emissions. Endless resources, such as solar energy or wind power have low emissions and will therefore be preferential in assessment of global warming. This is the same situation for waste heat that neither has any emissions but here aspects such as availability and alternatives use must be considered. Bio fuels that are renewable energy sources will also be preferential in assessment of global warming since their carbon dioxide emissions at combustion are considered as zero.

Also nuclear power will be preferential in assessment of global warming due to its low emissions to air even though the complete lifecycle of the energy source is considered. Nuclear power will, on the other hand, have serious environmental impacts of radiation and radioactive waste. In case of nuclear power plant accidents the environmental impact from nuclear power will be vital. The radioactive waste requires safe terminal storages, and these storages will be left for the next generations to take care of. The environmental impact from nuclear power is therefore very important but neither of its negative aspects will be reflected into the assessment of emissions to air at all.

6.2 Solar thermal systems

One of the main purposes of the Internet tool is to be a support for choosing heating system operated with renewable energy sources by showing their environmental advantages. Solar thermal systems are essential as alternative systems and this is also showed in the Internet tool as an option when specifying the mix of production units for district heating.

However, the Internet tool does not present solar thermal systems as heating system in domestic houses directly. This is due to that solar thermal systems seldom are sufficient during the whole year and they require an integrated solution with a solar collector in combination with another heating system.

An assessment of the integrated solution, by including the energy used for the combined heating system and not including the energy from the solar collector, will underestimate the advantage with the integrated solution. This is due to that the yearly efficiency of the combined heating system will often increase in the integrated solution and this will further decrease the environmental impact. This must also be considered in order to reflect the total advantage in the assessment.

For example, an oil boiler has its best efficiency when working at its nominal effect, which often corresponds to the design load for the building. Since the outside temperature mostly is below the design temperature, the yearly efficiency will become lower then the nominal efficiency. If a solar collector is installed the oil boiler can be shut off during the summertime when its efficiency is very low and this will increase the yearly efficiency. The value of efficiency is dependent on the length of the shut off period, the outdoor climate and the building's total energy need. Corresponding arguments can be used for integrated heating system such as pellets or wood boilers with solar collectors.

7. CONCLUSIONS

A method for environmental assessment of building's energy use has been developed and it has been programmed together with a database into a publicly accessible Internet tool.

The advantages with the Internet tool are:

- the life cycle of the energy source is considered,
- it has a large database with default data,
- it is easy to change default values when better values are known,
- it is easy and fast to use the tool, with only operation energy use as input,
- both assumptions, boundary conditions and calculations are transparent,
- boundary conditions for district heating and electricity can be chosen,
- objective results of total emissions and environmental effects,
- with the above advantages, the user can do the evaluation based on the judgments that are relevant for the specific assessment.

The disadvantage with the method is that the most significant environmental impact from nuclear power is not reflected in the environmental assessment.

The Internet tool could be further improved by adding the possibility to do assessments of the total environmental advantage with an integrated solution with solar thermal systems in combination with another heating system.

8. ACKNOWLEDGEMENT

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