ENVIRONMENTAL IMPACT AND LIFE CYCLE ASSESSMENT OF HEATING SYSTEMS

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ABSTRACT

During the design process of heating systems, the designer must analyse various factors in order to determine the best design options. Therefore, the environmental aspects of a product should be included in the analysis and selection of design options if an environmentally - aware design is to be produced. If one wishes to assess a product's environmental impact, its whole life cycle must be studied. The Life Cycle Assessment (or LCA) methodology is an example of one kind of environmental analysis which included the entire life-cycle of a product. However, this method has some limitations. It is unable to tackle the total total environmental impact on a number of different levels (e.g. materials, energy, waste) at the same time. To overcome some problems in the LCA method, an alternative method, the so-called Eco-Indicator method has been proposed. Since it is based on a weighting method, only a single score for the total environmental impact is calculated. The application of this method for the optimisation of heating systems is presented in this paper. The result permits the user to see how much environmental impact of these design alternatives will have. The designer can analyse the consequences of an idea quickly and effectively and establish clear selection criteria for an idea.

KEYWORDS

Heating system; Life cycle analysis; Environmental impact, Impact assessment

INTRODUCTION

Sustainability has become a global issue by increasing awareness that there are limits to the availability of non-renewable resources and that there are limits to the nature's ability to adsorb wastes. Several concepts and tools for achieving a more sustainable future have been developed. The tools include environmental impact assessment (EIA), strategic environmental assessment (SEA), life cycle assessment (LCA), positional analysis (PA), cost-benefit analysis (CBA), material intensity per unit service analysis (MIPS), total material requirement analysis (TMR), ecological footprint (EF), exergy analysis, emergy analysis and risk assessment. Whereas the energy is used in operating a building, the energy-based tools are applied, e.g. Bejan et al (1996), Bakshi (2000), Bastianoni et al (2000), Gong (2001). Similarly, the environmental impact of building services systems and products depends on the environmental burdens from the production processes. Buildings contribute 15% to 45% of the total environmental burden for each of the eight major LCA inventory categories. In any design, trade-offs must be made among solutions aimed to optimise building performance for various objectives. Environmental objectives are diverse, complex, interconnected, and frequently conflicted. Decision-making tools such as multiple attribute decision analysis can assist designers and their clients resolve conflicting project goals that normally are part of any project.

A major goal of these study is to present the consequences of designer's choices during the design phase. Selecting and designing of heating and air-conditioning systems affects the costs and the environmental impacts. This study dealt with effects of selecting the heating system as a part of building services systems of a dwelling in a residential building. The work was carried out by studying alternative combinations of heating systems in model building. In the study the LCA methodology was used. It has become one of the most actively considered techniques for the study and analysis of strategies to meet environmental challenges. The strengths of LCAs derive from their roots in traditional engineering and process analysis. Also vital is the technique's recognition that the consequences of changes in technological undertakings may extend far beyond the immediate, or local, environment. A technological process or a change in process can produce a range of consequences whose impacts can only be perceived when the entire range is taken into consideration.

LIFE CYCLE AND ENVIRONMENTAL IMPACT ASSESSMENT

Life cycle assessment is defined by ISO 14000 series standards and is conducted by compiling an inventory of relevant inputs and outputs of a product system by evaluating the potential environmental impacts associated with the inputs and outputs and by interpreting the results of the inventory analysis and impact assessment phases. The LCA covers the whole life of the product; the study begins from the raw material acquisition through production, use and disposal. An LCA starts with a systematic inventory of all emissions and the resource consumption during a product's entire life cycle. The result of this inventory is a list of emissions, consumed resources and non-material impacts like land use. This table is termed the inventory result. Since usually inventory tables are very long and hard to interpret, it is common practice to sort the impacts by the impact category and calculate a score for impact categories such as greenhouse effect, ozone layer depletion, and acidification. Once the category indicator results are generated, additional techniques are used to analyse the category indicator results (normalisation) and the valuation process to aggregate across impact categories (valuation or weighting). How these impact categories are to be weighted is much less clear. For this reasons it is frequently the case that the result of an LCA cannot be unambiguously interpreted. To solve this problem a more complete impact assessment methodology (LCIA), followed by a weighting step, is needed. LCIA normalisation implies the normalisation of the indicator result by dividing by some reference value.

The importance of the LCA approach, including the LCIA phase, lies in LCA's key feature – a system-wide perspective and the use of inventory functional unit to normalize the data. Weighting is an optional element to be included separately to better understand the ecological consequences of results from the inventory analysis. This procedure, starting with the inventory result and then trying to interpret it, is referred to as the bottom-up approach. Another possibility is a top-down approach. The top-down approach starts by defining the required result of assessment. This involves the definition of term 'environment' and the way for weighting the different environmental impacts. The weighting of environmental problems is usually seen as the most controversial and difficult step in an assessment. The Eco-indicator method has resolved these problems as is described by Goedekoop et al (1993, 1995a). The LCA method has been expanded to include a weighting method. This has enabled one single score to be calculated for the total environmental impact based on the calculated effects, introduced by Kortman (1994) and expanded by Goedekoop (1998), as is schematically shown in Figure 1.

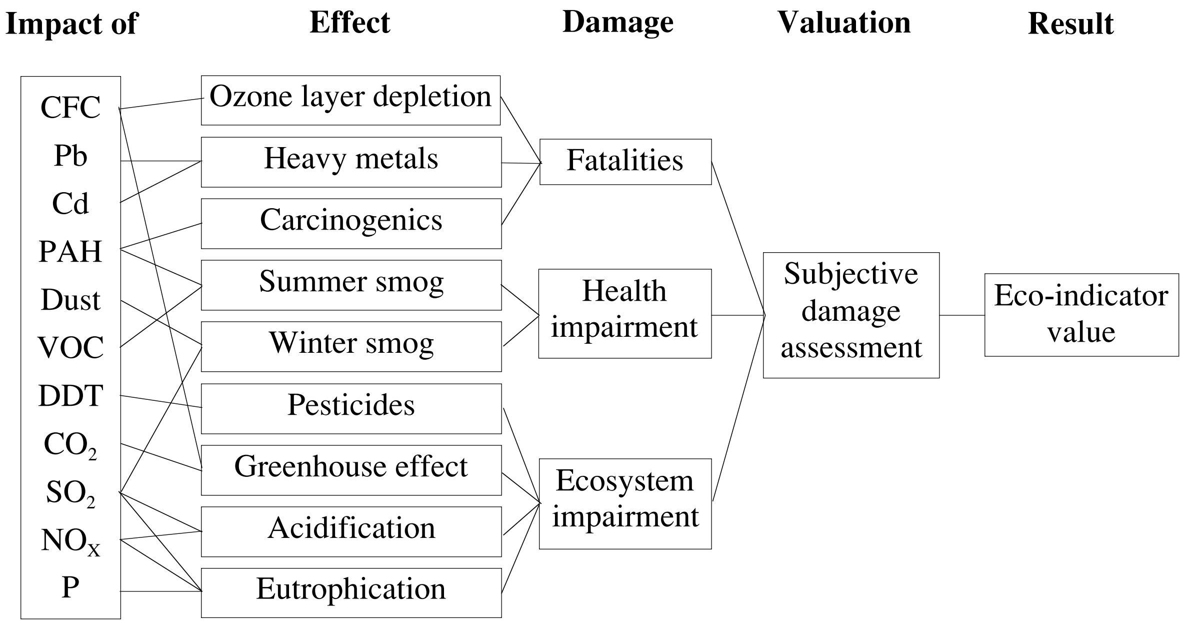

Figure 1: Eco-indicator weighting principle to assess environmental effect of a product

This principle has been in use for some years in the Swiss Ecopoints weighting system, described by Ahbe (1990). The underlying premise is that there is a correlation between the seriousness of an effect and the distance between the current level and the target level. An important advantage of the top-down approach is the ability to separate the really important issues from the not so important issues. In order to assess the overall impacts of trade-offs, the relative importance of various environmental problems must be determined.

CASE STUDY

According to the standard ISO 14040 the functional unit is generally defined as a quantified performance of a product system. The service provided by the heating was defined as the functional unit. The service was defined to be heating the dwelling in a model building to a temperature level of 21 ºC. The functional unit is the whole technical system, which is needed to fulfil the heating demand. However, instead of looking at the whole system, also functionally equivalent alternative parts of the system can be studied. Thus the functional unit (quantitative capacity of the product system) could be the heat output, provided by the heating system. If the required amount of heat with regard to heat consumption can be produced with help of alternative heating system, the corresponding alternative product system can be dealt with as comparable unit. The study included the environmental impact at the production phase, because alternative production methods have different kinds of environmental burdens. The environmental impact of energy production for residential heating is excluded from the analysis, since it is not the environmental impact of a heating system as is, but the environmental impact, which comes from the use of building.

The model building was a single family dwelling in a residential building. The calculated total heat demand of a dwelling equipped with the heating system was 11,8 kW. Heat demand of the dwelling and heating systems were calculated and dimensioned according to relevant standards. In the presented case study, the computer program (Dendrit) was used for the calculations. Also the dimensioning of heating systems was done by the standardised procedures, e.g. DIN 4701 for heating load, EN 422 for radiators, EN 1264 for floor heating.

The LCA study’s boundaries were set to the materials of the heating systems, to the use of energy during production phase and to the environmental burdens caused by production. The disposal or recycling of the heating systems was not included in the examination, since different scenarios for the same system yield to different results and due to the consumer’s behaviour. The comparison between three different heating systems was made with Eco-indicator 95 method. The indicator values for the materials (and processes) are derived from the design specifications, using the values from Goedekoop (1995b).

Radiator heating

In the case of radiator heating system, two different systems are analysed. The main difference was the chosen material for piping system (steel / copper) and for radiators – heating panels (steel / aluminium). In Figure 2 is presented the result of analysis for steel radiator heating with steel pipes, made by Eco-indicator method. The results reveal the great importance of radiator (greater mass of radiator than pipes), which presents the 70 % of overall impact. Total Eco-indicator is 1,359 Pt. The results of similar analysis for heating system with aluminium radiators and copper pipes are shown in Figure 3.

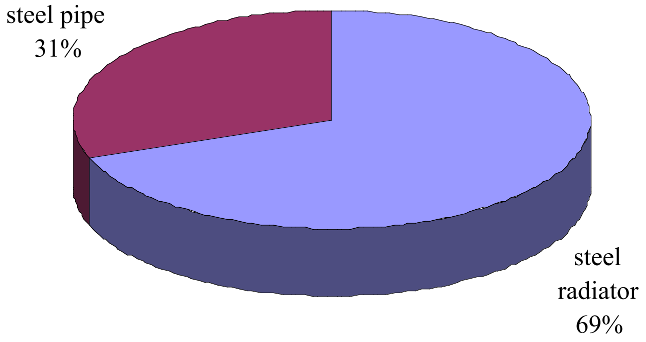

Figure 2: Eco-indicator values for steel radiator heating; pipe length: 78,4 m; material for radiator: 0,947 Pt ; material for pipe: 0,412 Pt ; total: 1,359 Pt

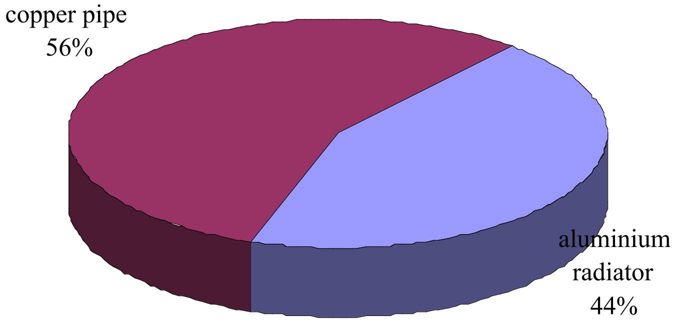

Figure 3: Eco-indicator values for aluminium radiator heating; pipe length: 78,4 m; material for radiator: 1,774 Pt; material for pipe: 2,234 Pt; total: 4,0 Pt.

As it is seen from Figures 2 and 3, the copper pipes for aluminium radiator heating are dominant among the materials for environmental impact. Copper pipes represents 56 % of overall impact for the given example, despite smaller dimensions. Total Eco-indicator is 4,0 Pt, and is much more as for the steel system.

Floor heating

Eco-indicator value for polyethylene pipes, dimension 14×2, is 0,089 Pt and for polybuten pipes (PB), dimension 16×2,2, is 0,111 Pt. Pipe length was 291 m and was the same for both systems. Difference was only in pipe material, while all other parameters were the same. While the heating demand is the same regardless the heating system, analysis results are comparable to other systems, since they are expressed in the form of Eco-indicator points. Smaller (better) eco-value for floor heating system is also the consequence of the fact that the extra building construction was not considered.

Fan coil convector

For the analysis, the exposed floor fan coil convector unit was chosen with average parts. The base unit is made of 1,0 mm thick galvanized steel plate. Cold panels are insulated. The fan section is composed of a cross-flow tangential fan and special air discharge sections that ensures a uniform distribution of the airflow. The three-speed motor is mounted on flexible supports. Cabinet is made in five separate pieces, a front panel in 1 mm thick galvanized steel and painted with a durable baked polyester powder coating. Pipe coil is a copper tube and lanced aluminium fin construction. The convectors were chosen in accordance with heating power. The convectors are substitute for radiators. For piping system, one could assume the same conditions as for the radiator heating system. The performed analysis was made for different materials. Since the fan coil unit consists from various parts, we could determine the Eco-value for different part. In Figure 4 is shown the Eco-indicator value for different materials, used for different parts of fan-coil units. From these figures the influence of different materials in different parts of unit is obvious.

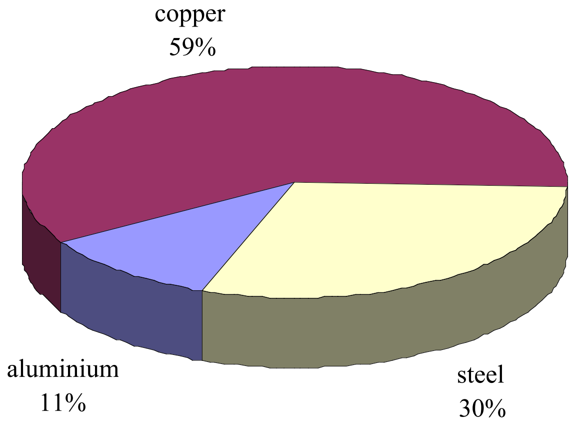

Figure 8: Eco-indicator value for fan coils (convector heating / cooling), by materials; total 3,126 Pt

In Figure 4 is presented the result of analysis for fan coil units. Heat exchanger is made of aluminium plates and copper pipes, which contributes the greater Eco-indicator (50 %). Total Eco-indicator is 3,126 Pt.

4. Conclusion

The Eco-indicator 95 method has been used for the analysis and optimisation of heating and air conditioning systems. This method enables environmentally aware design and is open working method with a platform on which both industry and science can integrate the environmental aspects into the design process. The result permits the user to see how much environmental impact of these design alternatives will have. The designer can analyse the consequences of an idea quickly and effectively and establish clear selection criteria for an idea.

This research showed that three different concepts of heating systems with different construction materials vary the Eco-indicator value. We can see that for radiator heating system the Eco-indicator value is far superlative than for floor or fan coil convector heating system. Copper pipes and other copper parts contribute to the greatest environmental impact. Radiator heating Eco-indicator (1,359 Pt – steel pipes and 4,0 Pt – copper pipes) showed three times higher value for copper pipes than for the steel pipes despite smaller dimensions. The lowest values are obtained for floor heating systems, but no extra building construction was considered. Reasonable values are obtained for fan coil units (convector heating/cooling) with Eco-indicator value 3,126 Pt. Analysis show up, that heat exchanger (copper pipes) contributes the main part of the value. Nevertheless, the environmental aspect is only one of the evaluation criteria in addition to cost, aspects of use and standards.

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