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Environmental evaluation of an air-conditioning system supplied by cooling energy from a bore-hole based heat pump system

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Abstract

An evaluation of the environmental impacts of an air-conditioning system which uses a bore-hole system for heating and cooling is the aim of this case study. To facilitate the evaluation, the bore-hole based air-conditioning system is compared with a reference system that uses a more traditional source of heat (district heating) and cooling energy (refrigeration). Environmental impacts of the system are examined by the life cycle assessment (LCA) method, including the weighting step. Results show that the bore-hole based system performs better in three of the four impact categories investigated: acidification, eutrofication, and global warming potential (GWP) with a 100-year horizon. This is mainly due to the fact that it uses less material in the production phase and less operating energy during the user stage. However, in the category of photochemical ozone creation potential (POCP), it performs four times worse than the more traditional system. Nevertheless, the overall environmental impact of the bore-hole based system, evaluated by common weighting methods, is better than the more traditional system. The most dominant environmental impact of both systems arises from the operating energy, although the energy use in the building studied is low.

Keywords: Environmental assessment; Life cycle assessment (LCA); Air-conditioning system; Bore-hole based heat pump; Comfort cooling system; Office building

1. Introduction

Evaluation of the environmental impacts of an air-conditioning system with a bore-hole system as a source of heat and cooling energy is the aim of this case study. The air-conditioning system in combination with a bore-hole system is stated to use only one-third of the energy required by a more traditional system, for example a refrigeration machine and district heating. The low operating energy demand contributes to a significant reduction of environmental impacts, since the energy use is often the largest contributor to the overall environmental impacts of an air-conditioning system [1].

However, the environmental performance of this system could be affected by parameters other than the energy use. For example, the bore-hole based system needs additional materials for components, such as bore-hole pipes, and the system requires more land for the placement of bore holes as well. Both additional materials and the increased land use affect the total environmental impact. Hence, the environmental evaluation of this more complex system should take into account the whole life cycle of the system, not just the user stage represented by the operating energy use. Therefore, both the production stage represented by the material and the end-of-life scenario for the disposal of the system are included in the analysis.

This analysis intends to evaluate the environmental performance of a bore-hole based air-conditioning system which is designed with respect to low energy use during its entire lifespan. The study is based on a real air-conditioning system which has been in operation since the spring of 2004. The technical performance of this system was monitored from May 2004 to September 2005. The bore-hole based air-conditioning system is compared with a reference system designed to meet the same requirements, but with more traditional sources for heating (district heating) and cooling (refrigeration).

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2. Method

The environmental impact of two air-conditioning systems is studied by the life cycle assessment (LCA) method, including the weighting step.

2.1. Life cycle assessment method

The LCA method is standardised in ISO 14 040 [2]. According to the standard, each LCA study is divided into four separate phases: goal and scope, inventory analysis, impact assessment and interpretation. The form and content of each phase are defined by the following standards: ISO 14 041 [3] for the goal and scope, and for the inventory analysis; ISO 14 042 [4] for the life cycle impact assessment; and ISO 14 043 [5] for the interpretation.

In the goal and scope phase, the purpose of each study is to be defined, and the intended application of the results should be indicated, as well as the audience. Therefore, the product or the system to be studied should be defined and its function has to be described, which is of particular importance in comparative studies. A *functional unit*, which is a quantified performance of the product or system studied, has to be defined. In applications of air-conditioning systems, for example, the function is to achieve a specific indoor climate in a particular building. The required indoor climate thus defines the design parameters for air-conditioning systems. Technical performance of the system is subsequently modelled for the particular building; given weather data as well as activity are included. Hence, heat and cooling loads (kWh/year) can be estimated. The modelling also determines the required airflow (given in m^3/s) at a specific temperature (°C), relative humidity (%), or both. It also indicates the required operational time (hours/year). The functional unit can be specified by a suitable combination of these parameters. However, the same desired indoor climate has to be achieved by all alternative systems studied.

Inventory analysis is the second phase of an LCA study. Here, all data related to the functional unit are collected; i.e. all materials and energy inputs and outputs. The data are usually given in mass or energy amounts (in kg or kWh). The inventory results are used in the third phase of the LCA, the impact assessment, which examines the potential environmental impacts caused by the product investigated. In the interpretation phase of the LCA, information from the earlier phases is analysed in order to reach conclusions and recommendations.

2.2. Usage of LCA based weighting methods

Weighting is an optional element of impact assessment. Weighting is the process whereby the various environmental impacts of a product are converted to an overall environmental impact by assigning weights to the different impact categories. The conversion process uses value-choices, based on the preferences of the valuators. Thus, variation in preferences may make the results of one LCA study differ from that of others. This is why it is desirable to use more than one weighting method and to assess their impacts on the inventory results [4].

Application of the LCA based weighting method in this study is in accordance with the aim: to evaluate the environmental performance of the air-conditioning system. The weighting results here are employed as additional information for decision makers. They are also intended to provide designers with information about how the environmental impact of a system is allocated to its various components, and thereby to enable improvements of the environmental performance. In addition, the LCA may be a part of external communication between the design company and their clients, for example in the form of environmental declarations about the system. For this, however, the life cycle inventory results should be presented before the weighting step.

3. LCA of a bore-hole based air-conditioning system

The air-conditioning system studied was installed to provide a building complex with ventilating air which should also lead off the surplus heat from the premises. Heating of the premises, provided by a separate water loop heating system, is not included in the scope of this study.

The building complex, which is owned by the real-estate company *Akademiska Hus AB* in Göteborg, is intended for the offices and teaching facilities of medical departments at the University of Göteborg. The complex consists of two buildings: an old high-rise block, for anatomy sciences, which is being renovated, and a new building, known as *Academicum*. The gross area of the premises is 5000 m^2, or 2500 m^2 for each of the buildings. In each of the buildings, a new all-air, air-conditioning system has been installed. The source of heating and cooling energy for the building complex is a bore-hole based heat pump system.

To be able to study the environmental performance of an air-conditioning system that is designed for low energy use during its lifespan, and to avoid trade-offs that might be made due to limited space in existing buildings, only the air-conditioning system for *Academicum* is included in this analysis.

3.1. Goal and scope

The purpose of this study is to evaluate the environmental impact of the bore-hole based system (System A) taking into account its entire life cycle. Results of this study are intended to provide both designers and decision makers with relevant information about the environmental performance of this system, and thus to enable them to identify possible modifications of the system design to improve the environmental performance of similar systems. The bore-hole based air-conditioning system is compared with a reference air-conditioning system (System B).