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Comparative evaluation of different computational models for performance of air source heat pumps based on real world data

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Abstract

To reduce energy usage and CO_2 emission due to heating, heat pumps have turned out a good option. For example, to obtain a net zero house, often a combination of solar panels and a heat pump is used. A computational model of the performance of a heat pump provides a useful tool for prediction and decision making. In this paper, six variations of such computational models are discussed and evaluated. Evaluation was based on real world empirical data for 8 different domestic situations. The evaluation took place by determining the most optimal values for the parameters of each of the models for the given data, and then considering the remaining error.

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Keywords: domestic energy usage; renewable energy; air source heat pump; seasonal performance factor

1. Introduction

In designing or renovating houses, often an aim is to come as close as possible to an energy neutral or net zero house; e.g., [1, 2]. In a net zero house, on an annual basis the total amount of energy used by the building is roughly equal to the amount of renewable energy it produces. Usually a photovoltaic (PV) solar energy production system is

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used, in combination with a heat pump; e.g., [3–7]. Computational models for the performance of both heat pumps and PV systems are useful as a basis for the decision on the dimensions of both systems.

The energy demand for heating a house depends on the ambient temperature. For traditional gas-, oil- or coal-based heating systems it is common to model the heating demand in a linear manner as a function of the outdoor and indoor temperatures, proportional to the number of degree days. These are based on the integral of the differences of indoor and outdoor temperatures over time, as long as the indoor temperature is higher than the outdoor temperature. Such linear relations between energy usage and indoor and outdoor temperatures make it easy to aggregate and average the usage over time. For example, the average energy usage over some time period can be determined on the basis of average indoor and outdoor temperatures over this period.

For an air-to-water heat pump as considered here, the energy usage also depends on the energy demand and through that on the indoor and outdoor temperatures, similar to the traditional cases of heating. However, an important difference is that also its efficiency of heating (expressed as its Seasonal Performance Factor, SPF) depends on a number of dynamic situational factors such as the outdoor temperature, humidity and the frequency at which the compressor is working. Among these, the outdoor temperature has the most important effect on SPF. Therefore in the overall relation between energy usage and temperatures, these temperatures have a double, nonlinear effect on energy usage: on the one hand through the energy demand expressed via degree days, and on the other hand through the performance factor. As a consequence, taking averages over longer time periods cannot be used as they do not provide adequate estimations. For every occurrence of an ambient temperature the energy usage has to be calculated separately, for example, by simulations per hour or per day.

In this paper, six different variants of computational models for air source heat pump performance are considered. Each of these models has a number of parameters that have to be estimated for a given situation. A data set was obtained from the Website www.liveheatpump.nl. Using simulation over hours and a parameter estimation approach to tune the values for the parameters, the most optimal values of its parameters were determined for each of the models. As error function, the square root of the average of the squares of the deviations for all time points was used. The remaining error after this parameter tuning was used as a comparison measure for the models.

In the paper, first in Section 2 some background theory on heat pumps is presented. Section 3 describes the used dataset. In Section 4, the computational models are presented. Next, in Section 5 it is shown how parameters of models have been estimated based on numerical techniques and empirical data. This provides well-tuned models of the performance of the heat pump in the given house. In Section 6, the results are compared. Section 7 includes a discussion and future directions. The last section provides conclusion.

2. Background

2.1. Heating by Renewable Energy: Heat Pumps

In colder areas a substantial amount of domestic energy usage during the winter season is spent on (space) heating of the house; e.g., [8]. Traditional heating systems are usually based on non-renewable resources such as gas, oil, and coal, which are not sustainable as only limited amounts of them are available. Besides, they have serious negative effects on the environment and climate. Therefore alternative domestic heating systems get much attention nowadays, such as the use of a heat pump (e.g., [3–7]). A heat pump takes thermal energy from the environment (from air, water or soil) and uses this to heat the water of a central heating system in the house. To do this, it uses an amount of electrical energy to run the heat pump, which is only a fraction of the provided heating energy. Since surface water (like a lake or a river) is not available everywhere, and installing ground source heat pumps needs a big investment, many domestic heat pumps harvest their energy from the air (air source, or air to water heat pump). This is the type of heat pump considered in this paper. An important issue here is that on the coldest days, when heating needs most energy, the air temperature is low, and due to that an air to water heat pump becomes less efficient in use.

The performance of a heat pump is described by the seasonal performance factor (SPF), which indicates how much electrical energy (in kWh) is needed (to run the heat pump) as input to get a certain amount of heating energy as output for the heat pump over a certain time period or a season (e.g., [6, 7]):