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Air-to-air heat pumps in real-life use: Are potential savings achieved or are they transformed into increased comfort?

Kirsten Gram-Hanssen[a,*], Toke Haunstrup Christensen[b], Poul Erik Petersen[c]

[a] Danish Building Research Institute, Aalborg University, Department of Town, Housing and Property, Dr. Neergaards Vej 15, DK-2970 Hørsholm, Denmark
[b] Danish Building Research Institute, Aalborg University, Denmark
[c] IT-Energy A/S, Denmark

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ABSTRACT

This paper deals with individual air-to-air heat pumps in Danish dwellings and summerhouses and the question of to what extent they actually deliver savings of energy consumption. Results show that 20% of the expected reduction of electricity consumption is converted into increased comfort in the homes, including extended heating areas, keeping a higher temperature and a longer heating season and using the heat pump for air conditioning. Data include electricity consumption in 185 households before and after installation of heat pumps together with survey results of 480 households. Furthermore, 12 households were selected for in-depth analysis including technical inspection and qualitative interviewing. Especially for summerhouses, results indicate that on average there is no reduction in electricity consumption, as energy efficiency is counter balanced by increased comfort and changed heating practices. These results have to be taken into account when making long-term energy planning for a sustainable energy system.

1. Introduction

The sale of air-to-air heat pumps has been quite high, notably in Norway where some hundred thousand have been sold [1], but also in Sweden and France growing sales figures for heat pumps are reported. In Sweden, the domestic sale of heat pumps rose from approx. 20,000 to 80,000 per year between 2006 and 2007 and in France from approx. 50,000 to 70,000 per year [2]. Studies from several different European countries have pointed out that there are good economic reasons for consumers to install air-to-air heat pumps [3–5]. The question of what role air-to-air heat pumps play in a future sustainable energy system has to be discussed together with other technical changes of the whole energy system including to what extent electricity is produced by renewable energy [6,7] and to what extent the building stock is energy renovated [8]. Replacing direct electric heating with air-to-air heat pumps is, however, always more energy efficient, because heat pumps can provide 2–5 times more heat than the electricity they use as driving force [3]. Thus, in a scenario for future 100% renewable energy systems in Denmark, individual heat pumps are included for areas not covered by district heating [9]. From a socio-technical point of view it can, however, be expected that the full technical potential for energy efficiency will not be met due to changes in user practices towards still higher expectations and norms of comfort [1], as is also known from studies of other types of household technologies [10]. Within a techno-economic perspective the corresponding phenomenon is known as the rebound effect, which focuses on how the economic gains that households get from implementing more efficient technologies are used to increase consumption in other areas or within the same area resulting in higher standards and thus increased energy consumption. There has been a debate about the size of the rebound effect within the household sector, and a recent review suggests a rebound effect of 20%, meaning that 20% of the energy savings gained from efficient technologies within the household sector are transformed into increased energy consumption and thus not realised as energy savings [11,12]. The purpose of the study presented in this paper was to analyse to what extent the potential reduction from the installation of air-to-air heat pumps is realised or converted into increased consumption. Furthermore, it was the aim to go more into detail with the explanation of precisely in which areas the increases in comfort are seen and to understand in more sociological terms why and how these changes occur.

By 2009, 8% of houses in Denmark [13] and 84% of summerhouses were heated by direct electric heating [14]. Summerhouses in Denmark are small detached houses or cabins often located in coastal areas. There are about 215,000 summerhouses in Denmark and approx. 7% of Danish households own a summerhouse. One fourth of these summerhouses are old and without modern facilities, whereas the majority of summerhouses built today are

* Corresponding author. Tel.: +45 9940 2291; fax: +45 4586 7535; mobile: +45 2360 5653.
E-mail addresses: kgh@sbi.aau.dk (K. Gram-Hanssen), thc@sbi.aau.dk (T.H. Christensen).

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equipped with modern facilities and technologies, including some kind of heating technologies [15]. Danish summerhouses have traditionally primarily been used during the summertime, however, with a higher building and installation standard of the summerhouses, it is becoming more normal to use them also during some weekends and holidays throughout the year. The majority of the summerhouses and permanently occupied dwellings that are heated by direct electric heating are not situated near city centres and thus reachable by district heating; the most relevant future heating supply for these homes is therefore individual heat pumps [9]. As these houses have not installed central heating based on water-borne systems, the economically most attractive choice most often is to install air-to-air heat pumps. Another argument for looking at air-to-air heat pumps in relation to changes in comfort norms is that they can easily be used for air conditioning as well. Air conditioning has until now not been the norm in Danish households; however, having available technologies installed in the home might contribute to changing this.

In the following, we first describe the methods of the study and then, in the main part of the paper, present findings and analysis for permanently occupied dwellings and summerhouses. In the conclusion, results are discussed in relation to the implications for interaction between heating technologies and renewable energy systems.

2. Methods

Data presented in this paper were based on a survey from 2010 of house owners in two Danish regions that have installed air-to-air heat pumps. The survey population of 2793 households was drawn from the customer lists of two Danish regional energy companies, which participated in this study. All customers with a heat pump installed in either their permanently occupied dwelling or their summerhouse received an invitation to participate in the survey. A sample of 681 house owners or 24.4% of the population completed the online questionnaire with questions on heating technology, heating practices, other electric appliances and characteristics of the household before and after the purchase of an air-to-air heat pump. The questions concerning summerhouses differed slightly from those concerning ordinary dwellings (permanently occupied houses). People were asked to indicate the type and brand of their heat pump and only households that were certain to have an air-to-air heat pump are kept in the analysis. This included 481 houses, 76 of which were summerhouses and this was the final sample that was used in the analysis of this article. In order to detect changes in energy consumption following the installation of a heat pump, the questionnaires were combined with available electricity metering data from the years 1990 to 2009 supplied by the energy companies. Some questionnaires were removed from this part of the survey if the year of installation of the heat pump was unknown, or if the installation year was too recent or too old to have metering data for at least one year before and after installation. This resulted in a data set of 138 questionnaires, 42 of which were for summerhouses. Finally, a follow-up survey was carried out among the summerhouse owners asking questions on how they kept their summerhouse heated in wintertime, as this turned out to be an important question (however, it was only possible to get in contact with 35 of the 76 summerhouse owners). These data sets are summarised in Table 1.

Regarding the question of representativeness, the population of 2793 households included all customers of the two regional energy companies, who had a registered air-to-air heat pump according to the customer lists. However, missing from this list were customers who had installed heat pumps on their own (and not by accepting an offer from the energy companies). As some of these customers might have installed inexpensive models bought in DIY centres, etc., which in some cases might even have been installed by unauthorised professionals, it might be expected that the survey population of this study had a general bias towards air-to-air heat pumps of a higher quality and working with a higher energy efficiency compared with the total population of air-to-air heat pumps in Denmark. With regard to age, there was an overrepresentation of older people in the sample with only 5.4% of the survey respondents with a heat pump in their dwelling being younger than 41 years (compared with 32.1% of the population in the regions) and 91% of the respondents with a heat pump in their summerhouse being older than 50 years (compared with 78% of all summerhouse owners). Furthermore, there was an overrepresentation of low-income households among the respondents with a heat pump in their dwelling; 45% have an annual income of less than DKK 400,000 (approx. EUR 53,000) compared with 34% of the house owners in the two regions (see also [16]). It was not possible to conclude whether the overrepresentation of older persons and low-income households reflected the actual socio-demographic characteristics of air-to-air heat pump owners or a methodological bias as no national statistics existed on heat pump owners. Still, when interpreting the results it should be kept in mind that the respondents were in general older and less affluent than the rest of the population.

Twelve respondents were selected for in-depth analysis including face-to-face qualitative interviews and technical inspections of their heat pumps. The aim of the technical inspection was to detect to what extent technical issues could explain the lacking reductions of electricity consumption. The technical inspections focused on visible conditions that might affect the efficiency of the heat pump: the condition of the evaporator/condenser (physical damage or dirt obstructing the airflow) and risks of "thermal short-circuit" due to the placing of the evaporator/condenser. The aim of the interviews was to provide detailed descriptions of the use of the heat pumps and how they had been integrated into the heating practices of the households. Respondents were chosen in order to ensure variety in the sample with regard to heating system, development in electricity consumption and household composition. The interviews lasted about 1 h each and were carried out as semi-structured interviews [17]. They were recorded and afterwards thematically transcribed and analysed.

Results from this project were presented previously in two conference papers, one focusing on qualitative material [16] and another focusing on quantitative material [18], whereas this paper includes both approaches. In the following, the analysis of the results is divided into two sections dealing with permanently occupied dwellings and summerhouses respectively.

3. Analysis of permanently occupied dwellings

3.1. Theoretical energy savings achieved from installing air-to-air heat pump

First it is relevant to estimate the reductions that could be expected in the electricity consumption of dwellings after the purchase of a heat pump. From technical specifications and tests of the performance of heat pumps at different outdoor temperatures, it is known that the Coefficient of Performance (COP) is highly dependent on the outdoor temperature. Tests have shown that COP varies between 2 and 4 when outdoor temperatures vary between −15 °C and +7 °C. The COP of the heat pumps included in this study was estimated to be approx. 3 based on assumptions of typical outdoor winter temperatures in Denmark [19]. Thus, a reduction of two thirds of the electricity used for heating would be expected when