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Impact of Technological Advancement on Adoption and Use of Residential Heat Pumps

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Abstract

Heat pump performance is always improving. Lower minimum operating temperatures and better performance curves are increasing both the number of hours of useful service and effectiveness while in use. We estimate the rate of technological development for residential air source heat pumps and their consequent rate of adoption using a system dynamics model. From the perspective of the use stage in life cycle assessment, energy savings and greenhouse gas emissions reductions are estimated. A substantial reduction in overall energy consumption is predicted, while greenhouse gas emissions are only reduced where electricity is generated with little or no fossil fuels.

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1. Introduction

In cold climates space heating is a necessity and also one of the largest residential energy needs. In Ontario, Canada approximately 62% of residential energy consumption was for space heating alone.[1] This energy is primarily supplied by natural gas, fuel oil, and electricity, with natural gas and oil furnaces making up almost three quarters of heating systems.[2] These fossil fuels account for 90.6% of residential greenhouse gas (GHG) emissions in Ontario in 2012, excluding electricity.[2] A reasonable goal may be to minimize their use, using instead a greater proportion of electrical energy, which in Ontario results in the emission of only 100g or less of CO2 equivalent per kWh generated.[3], [4]

Heat pumps can deliver approximately three (3) times as much heat as the electrical energy used to drive them. If 10% of the heating needs of Ontarians currently supplied by fossil fuels was instead supplied with heat pumps, we could expect a 30% reduction in energy consumption for heating, and nearly as great a reduction in greenhouse gas (GHG) emissions. But will this technology be adopted, and how can we encourage it?

Early work in the area of technological advancement began with the productivity increase associated with labour. It was found that with every doubling of production volume there was a 20% reduction in labour costs. This was specifically for the aerospace industry, which at the time was even more labour intensive.[5]

Today technological advancements still result in reduced labour costs, often through increased automation, but improved performance of the end product itself can result in better energy efficiency and reduced life cycle impacts as well. It is the development of air source heat pump (ASHP) technology that enhances their economic and environmental performance. In particular, there are two parameters we find most important.

First is the lowest feasible outside operating air temperature. With lower operating temperatures, heat pumps can be used for more of the heating season. Today the best commercially available models can operate at temperatures of

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-30 degrees celsius. However, at these temperatures performance is reduced and operating costs are higher.

The second parameter of interest is performance. How effective is a heat pump at a given outside temperature? Manufacturers often state coefficients of performance (COP), a measure of the heat energy moved into the home divided by the electrical energy required to operate the heat pump, in the range of 2 to 3 or more, on average over the heating season. Because the COP varies over both the range of operating temperatures and amongst different models of heat pumps, an aggregated estimate of performance is necessary to predict energy requirements over the geographic and temporal ranges studied.

These two parameters will allow an estimation of the costs of operation and their comparison with the costs of operating competing technologies. Expecting that the homeowner will act rationally and allow financial considerations to dominate their decision, we will try to predict the rate at which heat pumps will be adopted in Ontario.

Life cycle assessment began with single products. In this case the manufacturer could make a change and expect a reduction of impacts based upon maintaining their volume of production. In the case of heat pumps the performance of the technology is closely tied to its economic viability and individual home owners must decide whether to make the purchase. It is not the same as it was for Coca-Cola when they decided that there would be less environmental impact and lower cost in transporting bottles made of plastic instead of glass. The product remained the same, and sales volumes would not have been expected to change significantly.

System dynamics are applied to analyze the effects of technological development on adoption rate. That is, the number of heat pumps with given capabilities in service is not prescribed, but rather estimated based on the influence of their improving performance and consequent economic feasibility. Furthermore the calculation of energy consumption and heating requirements can also be modelled within the same framework. Stella version 10.1[6] made by ISEE Systems is the software chosen for this work.

2. Methodology

System dynamics is used to model situations where there is feedback in the system contributing to its evolution. In this case, as heat pumps are put into service their share of the heating system stock is increased. It increases at a given rate per year – the adoption rate. The greater the number of households with a heat pump installed the greater is the likelihood that other home owners will come into contact with members of these households or see their heat pumps in operation. This rate of contact coupled with the economic feasibility of using a heat pump affects the adoption rate. The loop is reinforcing. That is, the greater the number of heat pumps, the greater their rate of adoption and in turn the number of heat pumps will rise even more quickly.

This forms the main structure of the model. Economic feasibility is influenced by rate of technological development and the prices of energy in the forms of electricity, natural gas, and furnace oil. Future work may consider how residential energy prices may be affected by changing demand, but in this model it is assumed that the shift in heating technology use is insufficient to have such an impact.

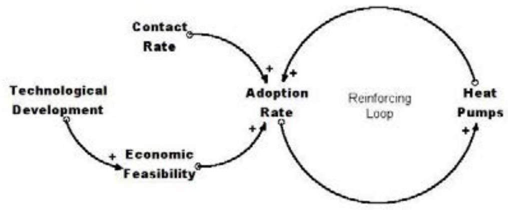

Fig. 1. Causal loop diagram of adoption of heat pumps.

Shown in Figure 2, is the stock and flow diagram of the main feedback loop shown above. This structure is based upon a model of infection rates in a population.[7] It exhibits “S” shaped growth. There is a slow adoption rate at first, but it accelerates as the number of heat pumps increases until finally slowing again due to reduced availability of households where a heat pump can be installed.

2.1. Economic Feasibility

In this initial study economic feasibility is determined only by operating cost. It is expected that if operating a heat pump costs more than readily available alternatives, very few home owners will install them. Furthermore, a homeowner contemplating the installation of a central air conditioning unit might consider a heat pump instead because the initial cost of purchase and installation is comparable, and a heat pump supplies not only summer cooling but also winter heating. It should also be noted that payback periods are irrelevant to the purchase of air conditioning systems where none were in service before.

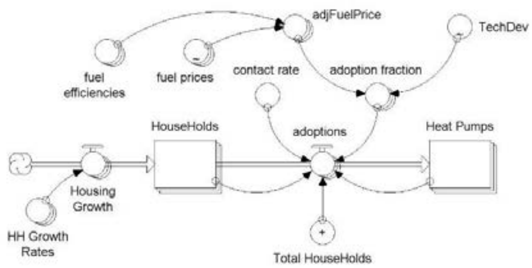

Fig. 2 Stock and flow diagram of adoption rate model.

The most important factor in determining the cost of operation is the price of fuel. While heat pumps use electricity, most furnaces in Ontario use natural gas and furnace oil. Both the historical and forecast prices of these three energy sources are shown in figure 3 for the years 2005 through 2025.