The Need for Subsidies in Adoption of High Efficiency and Renewable Energy Heating Systems

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Energy Policy and Economics

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April 20, 2011
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Introduction

Energy Performance of Buildings

In 2010, the European Parliament amended their directive on the energy performance of buildings, stating that by December 31, 2020, all new buildings in the European Union (EU) must be “nearly zero-energy buildings.” A nearly zero-energy building is defined by Directive 2010/31/EU (2010) as “a building that has very high energy performance.” Since buildings currently account for approximately 40% of all energy consumption in the EU, improved energy efficiency in the building sector would reduce overall demand and as a result increase energy independence in Europe. How are building designers and operators to achieve this reduction in energy consumption? According to Directive 2010/31/EU (2010), evaluation of energy performance in buildings should include “factors that play an increasingly important role such as heating and air conditioning.”

Micro Combined Heat and Power

Micro combined heat and power (mCHP) is one heat generation method that could play a significant role in nearly zero-energy buildings. Combined heat and power systems produce both heat and electricity to reach high overall efficiency (Energy Savings Trust UK, 2011). Coupled with heat storage and the concept of a Smart Grid, mCHP systems have the potential to lower peak energy demands and even provide opportunities for building owners to profit
from their local energy production.

Ground Source Heat Pumps

Excluding methods that make use of ties to the power grid, a ground source heat pump (GSHP) is another promising heat generation method. GSHP systems take advantage of the heat engine concept from thermodynamics, drawing heat stored in the ground at low constant temperatures and transferring it to the distribution system of a building at a higher temperature. Through this process, ratios of heating power output to electricity input are achieved far in excess of 100% (Energy Savings Trust UK, 2011). This raises the question: if these systems are so efficient, why are they not being implemented everywhere?

The Issue

Like many high performance systems, mCHP and GSHP systems have a higher initial cost than their traditional heating counterparts and are not suitable investments for many building owners. In response, Directive 2010/31/EU (2010) states that measures need to be taken to encourage investment in high performance systems, including direct subsidies or grant schemes. Subsidizing the purchase of high efficiency and renewable energy systems could bridge the financial gap and promote their adoption by building owners, but how much money will it take?

The Smart Grid concept and its relationship to future energy markets (particularly dynamic pricing) will be discussed. Further emphasis will be on the effects of government subsidies and their contribution towards the adoption of high efficiency and renewable energy heating technologies.
Smart Grid and the Energy Market

Smart Grid Benefits

The Smart Grid concept is a complex infrastructure of information and communication technology combined with improved accessibility and reliability of the power grid. In this futuristic system, distributed energy resources (DERs) in the form of local energy production (solar panels, combined heat and power, etc.) could be easily connected to the grid in large scales. Real time prices based on energy supply and demand would also be available to all users (NEMA, 2011). As a result, automated systems may be designed to operate building services to optimize costs. Services may include heating and cooling, as well as operation of appliances such as washing machines and dishwashers. All of these services could be designed to operate in a “Smart” way by planning operation to take advantage of low price periods and adapting to changes in real time.

Changes in cost correspond to times when energy demand differs in relation to energy supply. This type of pricing may be represented through a simple supply and demand plot as seen in Figure 1. In this example the supply is higher than demand, resulting in a non-equilibrium state for pricing.
Power Supply and Dynamic Pricing

In order to further discuss the power grid, it is important to understand the general planning strategy used in power supply. There are a few key players in the power supply chain.

The network operator schedules production based on energy estimates in order to meet the expected demand of its customers. To account for unavoidable changes in consumption, the power is produced for a network operator in three stages of hierarchical control (DERlab, 2010). The Primary Control is the first stage, purchased for long periods, and can make relatively slow adjustments to power output to stabilize frequencies in the system. The Secondary Control is then used to move the now stabilized production back to the correct frequency. The final stage is the Tertiary Control, where the highest costs are incurred.

If the unscheduled demand is going to last for an extended period of time, more energy production must be purchased. This could be large amounts, and is often supplied by burning coal which in turn has a negative impact on the environment.
Keeping in mind that all the power produced for the network operator must be either used or dissipated somewhere, and the complications involved in quickly adjusting power output, one can understand why it is in the interest of a network operator to adjust energy prices when there is a surplus of supply.

In the opposite case, when there is not enough energy, it makes sense for energy companies to pay customers to reduce energy consumption and compensate for increased usage by other consumers. This is one of the key interesting economic factors of a Smart Grid combined with local energy production and heat storage. Consumers are able to store or produce energy to use during peak power periods, reducing their consumption from the grid or even supplying power back to the grid to compensate for low supply (NEMA, 2011). In the process, building owners may even make profit. A simplified version of selling electricity to the current grid systems is discussed later in the mCHP model.
Effect of Government Subsidies on Supply and Demand

Demand Shift

The effect of government subsidies on supply and demand may be viewed from two perspectives: an upward shift in the demand curve, or a downward shift in the supply curve. In the case of direct grants offered to consumers purchasing high efficiency or renewable energy systems, it is more clear to view this as an upward shift in the demand curve. The upward shift corresponds to consumers being able to afford products at a higher price with the grant or subsidy covering the difference (Figures 2-3).

Based on these plots we can see what sort of general effect a subsidy may have on the market for high efficiency or renewable energy heating systems. At some cost to the government, the demand for these systems will be increased, and suppliers will also have increased profits, as seen in Figure 4.

Estimations

The issues that remain are to determine an appropriate representation of the price of a system (more complex than the initial cost), and an estimate of
how large of a subsidy would be required to make these systems attractive to building owners. These will be discussed in the sections that follow.
Figure 4: Supplier and Consumer gains due to subsidies.
Ground Source Heat Pump

Model

Background

As previously described, a ground source heat pump is a heat generation system that draws heat from the ground for use in buildings. The system works by circulating cold water through pipes in the ground (raising the temperature of the water) and then uses the heat pump to remove heat from the water and transfer it to the building. The advantage of a GSHP is that instead of creating the heat from another medium (e.g. natural gas), the heat is only transferred from one location to another (Energy Savings Trust UK, 2011). The ratio of heat output to the electrical power used by the heat pump is known as the Coefficient of Production (COP). Although the COP has a strong dependence on the temperature of the water and the temperature inside the building, a conservative COP estimate of 3.5 will be used for our GSHP.

RETScreen Software

The model for the ground source heat pump makes use of the software program RETScreen (Natural Resources Canada, 2011). RETScreen uses simplified models of heating (and other energy) systems, combined with weather data and user inputs to simulate energy comparisons among multiple configurations. It is used here to evaluate the typical yearly cost of a GSHP compared to
a traditional boiler heating system. A view of the user interface for RETScreen can be seen in Figure 5.

Figure 5: User interface of RETScreen software (Natural Resources Canada, 2011).

**Yearly Running Cost Calculation**

The ground source heat pump is compared to a typical boiler system of approximately the same power rating to determine the yearly savings. A gas boiler is considered, and average domestic natural gas and electricity prices are taken from Europe’s Energy Portal (2011) for the United Kingdom. See Table 1. Assumptions about the building and results from RETScreen can be found in Table 2.

<table>
<thead>
<tr>
<th>Source</th>
<th>Price (EUR) per kWh</th>
</tr>
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<tbody>
<tr>
<td>Natural Gas</td>
<td>0.0436</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.1447</td>
</tr>
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Table 1: Average price per kWh for Natural gas and Electricity in the United Kingdom (Europe’s Energy Portal, 2011)
As one can see, given the model assumptions, the annual energy bill for the boiler is 126 EUR higher than the heat pump. This looks like a reasonable gain, not only in cost, but also in energy usage with reduction by a factor of more than 3.5. The missing factor here is initial costs.

### Overall Cost Calculation

A typical high efficiency combination boiler system has initial costs of around 1200 EUR (WhatPrice.co.uk, 2011), whereas a GSHP with installation (including digging boreholes for the ground heat exchanger) can reach prices in the range of 10000-20000 EUR (Energy Savings Trust UK, 2011). For a simple analysis, let the initial cost of a boiler system be 1200 EUR and the initial cost of a GSHP be 15000 EUR.

\[
\text{Cost(EUR)} = 1200(\text{EUR}) + x(\text{Years}) \times 1272(\text{EUR/Year})
\]

\[
= 15000(\text{EUR}) + x(\text{Years}) \times 1146(\text{EUR/Year})
\]

\[x = 110(\text{Years})\]

From this simple calculation we see that after 110 years of operation the
overall costs of the two systems would be equal. Since the costs up until this point are always higher for the GSHP, this result already indicates an unfavorable situation. In order to make the calculation more accurate, it is important to take into account the time value of money (NSGIC, 2006). We would like to know the period of operation for which the Net Present Value of a typical boiler is equal to the Net Present Value of the heat pump system. Assuming a discount factor of 2.6% (NSGIC, 2006) and ignoring the lifetimes of each system, one can write the Net Present Value of each system as follows with $N$ as the total number of years operating.

$$\text{Net Present Value (EUR)} = -1200(\text{EUR}) + \sum_{t=1}^{N} -1272(\text{EUR}) \times \frac{1}{(1 + r)^t}$$

$$= -15000(\text{EUR}) + \sum_{t=1}^{N} -1146(\text{EUR}) \times \frac{1}{(1 + r)^t} \quad (2)$$

One can then simplify the geometric sum further, due to the assumption of constant yearly costs.

$$\sum_{t=1}^{N} \frac{1}{(1 + r)^t} = \frac{\frac{1}{1+r} - \frac{1}{(1+r)^{N+1}}}{1 - \frac{1}{1+r}} \quad (3)$$

The following equation then allows us to calculate the time period $N$ at which they are equal:

$$N = -\frac{\ln(1 - r\alpha)}{\ln(1 + r)}$$

$$\alpha = \frac{-15000 - (-1200)}{-1272 - (-1146)} \quad (4)$$

As can be seen in Figure 6 below, due to the discounting of future savings with the GSHP, a point of equality is never reached.

If a subsidy (in this case a direct grant) is introduced at the time of pur-
chase, the following behavior can be observed: With grants of approximately 9000 EUR and greater, it becomes possible to reach an equilibrium net present value for the two systems. As can be seen in Figure 7, the initial increments above 9000 EUR have the largest effect on the equilibrium period, with the incremental gains reducing as the grant approaches the full value of the GSHP. Figure 8 shows that with a grant of about 12700 EUR, the equilibrium period is 10 years.
Figure 7: Relationship between grant value and equilibrium period with respect to net present value of the boiler system and GSHP.

Figure 8: Difference between Net Present Value of a new boiler system and a GSHP given a 12700 EUR grant. Gains occur after approximately 10 years.
Micro Combined Heat and Power Model

Background

Micro-combined heat and power (mCHP) is a high efficiency heat and electricity generation system, often in the form of a combustion engine. The device burns fossil fuels such as natural gas in order to generate electricity, with the byproduct, heat, captured and used by the building heating system (Energy Savings Trust UK, 2011). This combination produces overall efficiencies of 90% and higher (WhisperGen, 2011). When combined with heat storage in the form of hot water storage tanks, a consumer is able to perform load shifting, selecting when to turn on the mCHP based on current prices and his own building demands.

According to Energy Savings Trust UK (2011), typical initial costs for mCHP systems are 5500 GBP (approximately 6250 EUR [Oanda, 2011]). A financial incentive also currently exists in some areas such as the UK and Germany called Feed-in Tariffs. Building owners are paid fixed amounts for each kWh of electricity they generate and a separate amount for each unit of energy they export to the grid (Energy Savings Trust UK, 2011).
Yearly Running Cost Calculation

The mCHP model will be compared to a standard natural gas boiler with a heat demand of 10 kW. The specifications from an example mCHP produced by WhisperGen (2011) will be used with RETScreen to calculate the energy usage. In addition, a constant Feed-in Tariff model will be used to calculate the gains from electricity sales (Energy Savings Trust, 2011). According to Energy Savings Trust UK (2011) the Feed-in Tariff in the United Kingdom is a total of 13 pence (0.1472 EUR [Oanda, 2011]) per kWh assuming all electricity is sold to the grid.

<table>
<thead>
<tr>
<th>Input</th>
<th>Value</th>
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<tbody>
<tr>
<td>Building Floor Area</td>
<td>200 m²</td>
</tr>
<tr>
<td>Heating Demand</td>
<td>50 W/m²</td>
</tr>
<tr>
<td>Domestic Hot Water Heating</td>
<td>20%</td>
</tr>
<tr>
<td>Boiler Seasonal Efficiency</td>
<td>95%</td>
</tr>
<tr>
<td>mCHP Heating Efficiency</td>
<td>82%</td>
</tr>
<tr>
<td>mCHP Heating to Electricity Output Ratio</td>
<td>10 : 1</td>
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Table 3: RETScreen (Natural Resources Canada, 2011) approximated inputs and outputs for mCHP model. *Note: Energy production and sales calculated using a fixed 10:1 ratio of heat to power output (WhisperGen, 2011), and 0.1472 EUR per kWh Feed-in Tariff (Energy Savings Trust UK, 2011).

Overall Cost Calculation

Similar to the calculation for the GSHP, for what period would the Net Present Value of running a typical boiler in our simple model equal the Net Present Value of the mCHP system? A discount factor of 2.6% is assumed and the lifetimes of each system are ignored.
Net Present Value (EUR) = $-1200 + \sum_{t=1}^{N} (-1343 \times \frac{1}{(1 + r)^t}$

$= -6250 + \sum_{t=1}^{N} \left( -1474 + 0.1472 \times 0.1 \times 27.7 \times \frac{1}{(1 + r)^t} \right)$

The key difference here between the GSHP and mCHP is that electricity produced by the mCHP (proportional to its heat demand) is sold to the grid.

![Figure 9](image_url)

Figure 9: Difference between Net Present Value of a new boiler system and an mCHP.

The period of operation before gains are made for the mCHP in Net Present Value over the boiler system is approximately 40 years (Figure 9). If direct cash grants during purchase were offered, this period would reduce as seen in Figure 10.
Figure 10: Relationship between grant value and equilibrium period with respect to net present value of the boiler system and mCHP.
Discussion and Concluding Remarks

Discussion of Results

The parameters and inputs used to simulate the two models in this paper were approximate values taken from various sources. In the following discussion, it is acknowledged that inaccuracies in these parameters may carry through to the general findings. Nevertheless, some interesting insights into the economic feasibility of high energy performance heating systems can be gained.

The most important result found was that when looked at purely from a cost perspective, the period before building owners would see gains without a government subsidy were high. In the case of the ground source heat pump, it was observed to be impossible, and with the micro combined heat and power system, approximately 40 years. For the GSHP, grants of about 12700 EUR would bring the period down to approximately 10 years and in the case of the mCHP, grants of around 3200 EUR would do the same.

From an energy perspective, the situation is more complicated. The mCHP system (with a heating energy usage of 33.8 MWh and a return of 2.77 MWh to the grid through electricity generation) had a net energy usage of approximately 31MWh compared to the boiler usage of 29 MWh. Although this seems like an overall loss, many factors concerning the origin of the electrical energy must be taken into account. Primary fuels such as oil or natural gas, are actually used
to produce electricity on the grid, with losses in conversion and transmission as high as 60% before the usable electricity reaches your home (WhisperGen, 2011). This means that the electricity produced and used locally could avoid some of this loss. The ground source heat pump energy usage is more than a factor of 3.5 times lower than that of the boiler system. Even considering the additional losses in the production and transmission of the electricity used to run the heat pump, there are large gains in overall energy efficiency.

**Extensions and Outlook**

In the future, with real time simulations of systems such as micro combined heat and power, it would be interesting to examine whether gains would be higher for owners selling electricity to the grid based on real time market prices or Feed-in Tariffs. According to Energy Savings Trust (2011), the Feed-in Tariffs for the UK are not guaranteed for an unlimited period, which may suggest that examining the real time price situation is important.

Current grant programs in countries such as Ireland have also been investigated. According to the Sustainable Energy Authority of Ireland (2011), building owners may be eligible for grants of approximately 3500 EUR for ground source heat pump installations. The analysis in this paper shows that this size of grant is likely not enough, based on cost, to justify selecting a heat pump system over a traditional boiler system. Research into the methods that governments use to select grant values, as well as the choice between situation-based grants (depending on the size of the installations etc.) and fixed grants would also be of interest to further the discussion.

The dedication of the European Union to promoting high efficiency and renewable energy systems is admirable. If the EU is able to meet its goal of nearly zero-energy buildings by 2020, it will be a great accomplishment, but it is clear that in order to make these changes economically feasible, subsidies must be created.
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