WHICH HEATER SHOULD I CHOOSE?

A comparative study of appliances and fuel sources

NILESH BAKSHI, ROBERT VALE, and BRENDA VALE
Victoria University of Wellington, Wellington, New Zealand
nlshbakshi@hotmail.com, robert.vale@vuw.ac.nz
brenda.vale@vuw.ac.nz

Abstract. This research investigates not just appliances, but also the wider system to include how energy is supplied. This is an important aspect, currently overlooked, as decisions made now may have to last through the transition to a low carbon society. This research investigates the life-cycle energy of heating with heat pumps, wood stoves and electric oil heaters. The study identified the most efficient models available to consumers for each type of heater, based on the Energy Star rating scheme and recommended products listed by the Ministry for the Environment. A constant heating regime for a single room was used as the basis of comparison. The research also looks at different ways of supplying electricity in New Zealand and the effect this could have on the life-cycle performance of the system.

Keywords. Heaters; electricity supply; life cycle impact.

1. Introduction

The EECA (Energy Efficiency and Conservation Authority) Energy End Use Database (EECA 2013) estimates that space heating accounts for about 29% of all energy consumed in a typical New Zealand home. Despite such figures, according to EECA the majority of NZ homes are under-heated compared to the World Health Organisation’s recommended minimum internal temperature of 18˚C, with a minimum of 16˚C in the bedrooms overnight. In New Zealand EECA also plays an important role in identifying technologies and appliances that promote energy efficiency, and the use of renewable sources of energy through the ENERGY STAR rating system. According to the EECA website (EECA 2013) the ENERGY STAR rating is awarded to the top 25% most energy efficient products available to consumers.
This research investigates the life-cycle energy use of heating with three appliances: heat pumps, wood stoves and electric oil heaters, identified by EECA as the three most common heating systems used in New Zealand (EECA 2013). Studies in other countries have shown that for a residential building the largest environmental impact is the result of the energy consumption for space heating (Keolian, Blanchard and Reppe 2000, p19) and (Ochoa, Ries and Hendrickson 2005). The situation is different in NZ, where space heating energy is roughly a third of all energy use, water heating another third, with the final third covering everything else (cooking, refrigeration, lights and appliances) (Isaacs et al 2006, p71). The three heating systems chosen for this investigation differ in their source of energy, the type of appliance, and the distribution system; hence, they will also be likely to vary in their environmental impacts. To investigate the extent of these variations, this research investigates not just the appliance, but also how the energy is supplied. The aim of this research is to determine what consumers should be investing in, and what is most appropriate for “one planet living” (Vale & Vale 2013, p321), a term used by Mathis Wackernagel as a two-word definition of sustainability (Wackernagel and Rees 1996). The study focuses both on the materials utilized in the production phase of the heating appliances and the impacts of operational energy consumption over the life of each system. A study by Heikkila (2004) compared the life cycle environmental impacts of gas and electric air-conditioning systems for an office building in Sweden, and found that the two air-conditioners had very different impacts. The differences in the source of energy dictate the relative environmental effects of the systems. Hence, it is likely that a careful selection of the type of heating system and its fuel can considerably enhance the environmental performance of a residential building. This study uses a life cycle assessment (LCA) framework (Lifecycle assessment - Principals and Framework 1997) to evaluate the three chosen heating systems and their source of energy. The installation of the systems at the site, the material waste resulting from the installation, and impacts associated with labour are not considered in the LCA. The systems studied are:

- The most efficient heat pump models based on their coefficient of performance as identified by the EECA ENERGY STAR system (EECA 2013),
- The most efficient wood stoves based on a Ministry for the Environment study (Ministry of Environment 2013), and
- The most commonly used electric oil heaters based on efficiency as identified by the EECA ENERGY STAR rating system.
2. Methodology and data sources

The analysis is performed using a process based approach wherein the life cycle energy of the systems is divided into two distinct phases: the embodied energy of manufacturing the appliance, and the operational energy utilised during the life of each appliance. The life cycle energy impact of the entire system is the combined impact of these two sub-phases. The materials required for the manufacturing of each appliance are determined and the embodied energy impact is based on the weight of each material incorporated into the appliance multiplied by its embodied energy coefficient in MJ/kg, using Alcorn’s data for NZ Building Materials (Alcorn 2003).

The materials for each system are determined from the manufacturers’ literature wherever possible. However, in the absence of a detailed material description from the manufacturer, the proportion and the weight of the basic materials is based on data collected in a life-cycle assessment of residential heating and cooling systems in four regions in the United States (Science direct 2007). The operating energy consumption of the systems is calculated including the embodied energy required for the production of the fuel for each system, thus identifying the ‘total operational energy’. In this case the fuels are New Zealand electricity and locally sourced firewood. Based on a 2009 study (Rule 2009), the New Zealand electricity mix consists of 55.2% hydro-electricity, 21.8% gas, 12.2% coal, 7.6% geothermal, 1.5% wind and 1.7% biogas, waste heat and wood. These figures were used for determining the total embodied energy of New Zealand electricity in kJ/kWh.

3. Embodied energy of the heaters

The 6 most efficient models for heating a single room were selected based on EECA and Ministry for the Environment figures. Table 1 shows the selected heat pumps with their coefficient of performance (COP) and the 10 year heating cost for each. The total kWh/annum were also determined.

<table>
<thead>
<tr>
<th>Top Brands</th>
<th>Model number (high wall unit)</th>
<th>Weight kg</th>
<th>Heat capacity (kW) 7°C</th>
<th>Heat COP at 7°C (H1)</th>
<th>10 year heating cost</th>
<th>Consumed kWh/Annum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitsubishi</td>
<td>SRK20ZJX-S</td>
<td>59</td>
<td>2.50</td>
<td>5.56</td>
<td>$1,707</td>
<td>648</td>
</tr>
<tr>
<td>Sair</td>
<td>SGT-09</td>
<td>50</td>
<td>2.85</td>
<td>4.72</td>
<td>$2,292</td>
<td>874</td>
</tr>
<tr>
<td>Daikin</td>
<td>FTXS25L</td>
<td>44</td>
<td>3.40</td>
<td>4.86</td>
<td>$2,657</td>
<td>1013</td>
</tr>
<tr>
<td>LG</td>
<td>R09</td>
<td>46</td>
<td>3.21</td>
<td>4.40</td>
<td>$2,769</td>
<td>1056</td>
</tr>
<tr>
<td>Panasonic</td>
<td>CS-E9NKR</td>
<td>42</td>
<td>3.60</td>
<td>4.80</td>
<td>$2,847</td>
<td>1085</td>
</tr>
</tbody>
</table>
The basic materials for the Mitsubishi heat pump are shown in table 2, together with the relevant embodied energy coefficients of each material (Alcorn 2003). Based on manufacturers’ literature, the life span of heat pumps is an estimated 15 to 20 years, but a 10 year lifetime is guaranteed for the given COP, thus the lifespan of these appliances is here assumed at 10 years. The final column gives an annual embodied energy figure for each material. It is assumed that that the refrigerant fluid used for all heat pumps is Isobutane (R-600a) a commonly used refrigerant. (Refrigerants 2013).

Table 2. Basic materials used in the Mitsubishi Heat pump. (Science direct 2007)

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight (Kg)</th>
<th>Embodied energy Coefficient MJ/kg</th>
<th>Embodied Energy MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron</td>
<td>37.9</td>
<td>70</td>
<td>2653</td>
</tr>
<tr>
<td>Galvanized Steel</td>
<td>12</td>
<td>34.8</td>
<td>417.6</td>
</tr>
<tr>
<td>Copper Tubing</td>
<td>6.4</td>
<td>70.6</td>
<td>451.8</td>
</tr>
<tr>
<td>Refrigerant Fluid</td>
<td>2.7</td>
<td>49.1</td>
<td>132.6</td>
</tr>
<tr>
<td><strong>Total (EE)</strong></td>
<td></td>
<td></td>
<td><strong>3655</strong> Total (EE)**</td>
</tr>
</tbody>
</table>

It is important to realise that this is only measuring the life-cycle energy of the heat pump and not dealing with other environmental impacts. In addition the study does not factor in the impact of a longer life for the heat pump, as it operates with a reduced COP as it ages. Based on a 10 year life for maximum operating efficiency, the annual embodied energy was calculated as in the equation below.

\[
\text{Embodied Energy of heat pump based on materials} \quad = \quad \frac{3655 \text{ MJ}}{10 \text{ years}} \quad = \quad 365.5 \text{ MJ} / \text{annum}
\]

This process was then repeated for wood stoves and electric oil-filled heaters. As shown in table 3 the basic materials required for the manufacture of a selected wood stove, including the flue, are similar to those of the example heat pump. However, the wood stove has a much longer life of 25 years, based on New Zealand manufacturers’ specifications, which gives a warranty of 10 years and an expected average life of 25 (Ablaze 2009).

Table 3. Basic material used in the Aber Holdings Wood Stove. (Science direct 2007)

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight (Kg)</th>
<th>Embodied energy Coefficient MJ/kg</th>
<th>Embodied Energy MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron</td>
<td>52.8</td>
<td>70</td>
<td>3696</td>
</tr>
<tr>
<td>Galvanized Steel</td>
<td>20.7</td>
<td>34.8</td>
<td>720.36</td>
</tr>
<tr>
<td>Glass</td>
<td>3.4</td>
<td>12.7</td>
<td>43.18</td>
</tr>
<tr>
<td><strong>Total (EE)</strong></td>
<td></td>
<td></td>
<td><strong>3811.5</strong> Total (EE)**</td>
</tr>
</tbody>
</table>
As there is no performance depreciation (as is the case with the COP for heat pumps) over the life of the stove, it is reasonable to assume the full expected average life for a wood stove. As expected the annual embodied energy of the wood stove is smaller, as seen in the equation below.

\[
\frac{\text{Embodied Energy of Wood Stove based on materials}}{\text{Assumed life of Appliance}} = \frac{3811.5 \text{ MJ}}{25 \text{ years}} = 152.5 \text{ MJ / annum}
\]  

As shown in table 4, the electric oil heater incorporates fewer materials. The assumption is that the oil used in the electric oil heaters is Shell HTO S2 oil (Shell 2009). As a result the embodied energy of the oil heater is much lower, as seen in its equation, this is negated by the shorter assumed life of 3 years as determined by the manufacturers (Dimplex 2009).

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight (Kg)</th>
<th>Embodied energy Coefficient MJ/kg</th>
<th>Embodied Energy MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>6.4</td>
<td>57.9</td>
<td>370.6</td>
</tr>
<tr>
<td>Nickel</td>
<td>1.6</td>
<td>92.5</td>
<td>148</td>
</tr>
<tr>
<td>Shell 320 oil</td>
<td>3.5</td>
<td>43.1</td>
<td>150.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>669.5 Total (EE)</td>
</tr>
</tbody>
</table>

\[
\frac{\text{Embodied Energy of Electric oil heater based on materials}}{\text{Assumed life of Appliance}} = \frac{669.5 \text{ MJ}}{3 \text{ years}} = 223.2 \text{ MJ / annum}
\]  

Shown earlier in table 1, the most efficient heat pump, according to EE-CA had a COP of 5.56 consuming 648 kilowatt hours a year to heat the room. In order to make a comparison based on the embodied energy of the appliance as well as the operation energy, the consumed kilowatt hours of this heat pump had to be converted to the supplied kilowatt hours of heat energy. This allows a comparison of all three heating systems in operation, supplying the same amount of heat.

\[
\text{Consumed kWh} \times \text{Coefficient of Performance} = 648 \text{ kWh / annum} \times 5.56 = 3604 \text{ kWh / annum}
\]

4. Operational energy consumption

The operational fuel consumption is calculated based on manufacturers’ literature. In order to determine the most efficient heating system based on total energy (embodied plus operational) per year, the heat energy in kWh per year was deduced based on the coefficient of performance (COP) of the Mitsubishi heat pump. This gave a total heat supply of 3604kWh/annum as
shown above. The annual energy consumption is assumed to remain constant for the entire life span of each system. The embodied energy of the fuel sources then had to be determined; the embodied energy of firewood was based on the delivered energy content of 16.2MJ/kg based on current timber production in New Zealand, (Sustainable Forestry 2007) and a 5 per cent embodied energy figure for wood pellet fuel (Wood Energy Knowledge Centre 2009). Based on the quoted efficiency of 69 per cent for the Aber Holdings Wood Stove, the appliance would require 0.89 tonnes of firewood to provide 3604 kWh of heat per annum. Therefore the energy content and total embodied energy of firewood can be determined as follows.

For both the heat pump and the electric oil heater, the current New Zealand electricity mix was used. As shown in table 5 the embodied energy of New Zealand electricity is 3008 kilojoules per kilowatt hour (giving an embodied energy coefficient of 0.84). The energy consumption will be converted to kilojoules or megajoules as appropriate. One kWh is 3600 kJ.

<table>
<thead>
<tr>
<th>Source of electricity</th>
<th>% of electricity mix</th>
<th>Embodied energy kJ/kWh</th>
<th>weighted embodied energy kJ/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro (pp. 6406)</td>
<td>55.2</td>
<td>55</td>
<td>3036</td>
</tr>
<tr>
<td>Geothermal (pp. 6406)</td>
<td>7.6</td>
<td>94.6</td>
<td>719</td>
</tr>
<tr>
<td>Wind (pp. 6406)</td>
<td>3.2</td>
<td>70.2</td>
<td>225</td>
</tr>
<tr>
<td>Gas (pp. 6412)</td>
<td>21.8</td>
<td>11537</td>
<td>251507</td>
</tr>
<tr>
<td>Coal (pp. 6412)</td>
<td>12.2</td>
<td>3714</td>
<td>45311</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td></td>
<td>3008kJ/kWh</td>
</tr>
</tbody>
</table>

The electricity generation mix is considered to remain the same throughout the life span of the appliance, this is an area that merits further research. As a result the total operational annual energy (EE of fuel plus fuel energy) of both the electric oil heater and the heat pump were determined as follows.
5. Results and interpretation

The embodied energy of the lifetime energy consumption for the three systems is presented in Table 6. As expected due to the heat pump’s COP, the fuel used is a fraction of that used by the electric oil heater using the same fuel source and supplying the same amount of heat as shown in figure 2. This indicates that the operational energy of heat pumps will have a smaller environmental impact than that of oil heaters.

Table 6. Embodied Energy of the lifetime energy consumption

<table>
<thead>
<tr>
<th>Total EE of Appliance</th>
<th>Heat Pump 556% efficiency</th>
<th>Oil Heater 100% efficiency</th>
<th>Wood Stove 69% efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE of Fuel</td>
<td>366 MJ</td>
<td>223 MJ</td>
<td>153 MJ</td>
</tr>
<tr>
<td>Energy Content of Fuel Consumed (kWh to MJ)</td>
<td>1,960 MJ</td>
<td>10,898 MJ</td>
<td>721 MJ</td>
</tr>
<tr>
<td>2.333 MJ (648 kWh)</td>
<td>12,974 MJ (3,604 kWh)</td>
<td>14,418 MJ</td>
<td></td>
</tr>
<tr>
<td>Total Energy of Operational Energy</td>
<td>4,293 MJ</td>
<td>23,872 MJ</td>
<td>15,139 MJ</td>
</tr>
</tbody>
</table>

As shown in table 6 and figure 2 the embodied energy for the wood stove and its fuel is a fraction of both the heat pump and the electric oil heater. These findings can be deceptive simply as they are based solely on the embodied energy of the fuel source and appliance materials. They do not consider the energy content of the fuel consumed by each appliance.

Figure 3 depicts the total embodied energy of the appliance and also the total embodied energy of the operation energy of these appliances. This ‘total Energy of Operational energy’ is depicted highlighting the two contributing components; the Energy of the fuel as well as the EE of fuel consumed. This
data now paints a clearer picture of the contributing factors that identify total energy of each appliance and energy source.

![Embodied Energy of Appliance & Total Operational Energy](image)

*Figure 3. Embodied Energy of appliance and Total operating energy.*

The electric oil heater is 100% efficient but the amount of fuel it requires means both the embodied energy of the fuel and its consumption result in the highest overall energy. The heat pump clearly has the smallest overall energy. Initially when looking at the embodied energy of each appliance's materials, the heat pump indicated the highest embodied energy value of the three. The more complicated technology behind this appliance allows it to function at 556% efficiency, which means it will require a fraction of the operational fuel. As a result one can deduce that the heat pump is best suited for heating as it uses the current electricity mix more efficiently than other systems such as the electric oil heater. Therefore the heat pump appears to be a far more sustainable choice out of the three systems investigated.

### 6. Conclusion

Three residential heating systems – heat pumps, wood stoves, and electric oil heaters – were compared using life cycle assessment. The aim of the study was to determine which common New Zealand heating system might be more appropriate for one planet living (Wackernagel and Rees 1996). The electric oil heater system has the largest footprint regarding both the appliance and the operational energy. The impact of electricity as the operational energy source dominates due to the relatively high embodied energy of electricity in New Zealand, as shown in table 5. This is where further research could begin to consider how this footprint would change if the New Zealand
electricity mix was altered, possibly to depend only on renewable energy sources.

Of the three heating systems evaluated, the heat pump has the lowest environmental impact on an overall energy basis. Even though the heat pump does not have the highest assumed life and also uses more materials in its complex design, the efficiency of the appliance means fuel usage is significantly lower. This is particularly significant as heat pumps use the current electricity mix that incorporates non-renewable sources for electricity generation, as a result far greater investment in a solely renewable energy mix in the future will likely make the overall energy of heat pumps smaller still.

In addition to environmental impact, additional criteria of carbon emissions, cost, comfort, fuel availability, constructability, and maintenance could be considered but have not been evaluated in this study.

7. Future research

Due to the fact that the aim of this paper was to determine which area of technology merits current investment, it can be argued that the fact that the highest footprint contributing factors are attributed to non-renewable forms of electricity generation makes it paramount to investigate an electricity mix based solely on renewable sources.

Another area for research would be the evaluation of other systems to provide comfort in New Zealand dwellings in the winter. One area of investigation is the life-cycle of putting more insulation into houses to reduce the need for heating as part of the overall heater/fuel/achieved comfort system.

Further research could also consider CO₂ (and other) emissions associated with the use of each fuel/energy type discussed in this paper.

Finally this research did not look at the embodied energy of transport, such as the transport of timber for burning in the wood stove. The embodied energy of the wood fuel was determined based on research conducted by Andrew Alcorn which looked purely at the process of harvesting and processing newly sourced timber in New Zealand. This merits further study as there are many sources that could be tapped for wood fuel in this country.

8. References


