Hot stuff or just a load of hot air?
My own experience of getting an air source heat pump

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Senior Technician
UCL-Energy Institute
March 2021
My house

“Eco-Excellent” house built in 2011 by major housebuilder
2-storey detached L-plan with 4 bedrooms
2 adult occupants (+ 2 cats)
Cavity masonry construction
153 m² gross floor area
Gas central heating (17 radiators, hot water cylinder, TRVs)
Flat plate solar thermal 2 m² (installed when built)
Evohome zoned controller & wireless radiator valves
Emonpi energy monitoring system
Solar photovoltaic 4 kWp
myenergi EDDI PV to DHW immersion diverter
myenergi ZAPPI 7kW car charger
Why did I want a heat pump now?

- To reduce my carbon emissions: grid carbon intensity predicted to be ~0.1 kgCO$_2$/kWh in 2030 (2020 gas and electric* both = 0.18 kgCO$_2$/kWh)
- Properly designed/installed ASHP potential SCOP of 4 = predicted net 100 kgCO$_2$/a in 2030 for house
- Thermal comfort + home working
- Get one while RHI still available
- Boiler ~9 years old
- Walk the talk
- Not doing it for cost (electric = 6x gas cost)

Source: Updated Energy and Emission Projections 2018, BEIS

How does a heat pump work?

**Vapour compression cycle**: apply work ($W_{in}$) to refrigerant to move heat ($Q_{in}$) from an environmental low temp source to useful high temp heat ($Q_{out}$). The Coefficient of Performance (COP) = $Q_{out} / W_{in}$
# Timeline

**JAN-FEB 20**
- Background research

**FEB-MAR 20**
- Contact installers

**20 MAR 20**
- Outline quotation

**APR-JUN 20**
- Installer discussions

**10 JUN 20**
- Heat loss survey

**15 JUN 20**
- Revised quotation

**JUL-AUG 20**
- Engineer visits

**11 JUL 20**
- Set up monitoring

**6-10 JUL 20**
- Heat pump installation

**1-5 JUL 20**
- Move garden gate

**16 JUN 20**
- EPC survey

**16 JUN 20**
- Accept & pay deposit

**3 SEP 20**
- Final commission

**4 SEP 20**
- Pay final invoice

**10 SEP 20**
- RHI application

**18 SEP 20**
- Handover pack

**27 SEP 20**
- Space heating on
## Heat pump choices?

<table>
<thead>
<tr>
<th>TYPE OF HEAT PUMP</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground source heat pump (brine to water)</td>
<td></td>
</tr>
<tr>
<td><strong>Monobloc air source heat pump (air to water)</strong></td>
<td></td>
</tr>
<tr>
<td>Split air source heat pump (air to water)</td>
<td></td>
</tr>
<tr>
<td>Exhaust air heat pump (air to air/air to water)</td>
<td></td>
</tr>
<tr>
<td>Multi-split air source heat pump (air to air, cooling)</td>
<td></td>
</tr>
<tr>
<td>Hybrid system (usually ASHP and gas boiler)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COMPRESSOR POWER CONTROL</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed speed</td>
<td></td>
</tr>
<tr>
<td><strong>Modulating inverter control</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MAXIMUM OUTPUT TEMPERATURE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Low temperature heat pump</td>
<td></td>
</tr>
<tr>
<td>(Max ~58°C)</td>
<td></td>
</tr>
<tr>
<td>High temperature heat pump</td>
<td></td>
</tr>
<tr>
<td>(Max ~65 to ~80°C)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MANUFACTURER &amp; PERFORMANCE &amp; MCS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>UK/Ireland (e.g. Kensa, Grant, Dimplex)</td>
<td></td>
</tr>
<tr>
<td>Europe (e.g. <strong>Vaillant, NIBE</strong>, Viessmann, Dantherm)</td>
<td></td>
</tr>
<tr>
<td>Japan/S.Korea (e.g. Daikin, Mitsubishi, Samsung, LG)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REFRIGERANT (ALL ZERO ODP)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R410a</strong> (HFC mix R32+R125(C₂HF₅), GWP = 2088)</td>
<td></td>
</tr>
<tr>
<td>R134a (HFC, C₂H₂F₄, GWP = 1300)</td>
<td></td>
</tr>
<tr>
<td>R32 (HFC, CH₂F₂, GWP = 675)</td>
<td></td>
</tr>
<tr>
<td>R290 (Propane, C₃H₈, GWP = 3)</td>
<td></td>
</tr>
</tbody>
</table>
Other considerations

- Heat pump compatible cylinder/store
- Heat emitters/pipework
- Controls/package/other heat sources
- Back-up heating/legionella control
- Buffer/volumiser/low loss header
Finding an installer

MCS certification?
Local?
Installer of NIBE or Vaillant?
Manufacturer accreditation?
Solar thermal?
Getting a response?
Availability?

Source: https://mcscertified.com/find-an-installer/
Outline quotation

- Only one installer responded
- Long term NIBE VIP installer
- Experienced in solar thermal
- Outline quotation based on simple data (house size, drawings, existing system specification and EPC) and my stated requirements
- Quotation used default flow temperature of 45°C
Heat loss survey & sizing

- Cost of survey £300 (refunded on order)
- Installer used official MCS calculator to size heat pump and radiators
- Design conditions: outside -2°C, inside 21°C
- Asked installer to size for 35°C flow but some radiators too big, had to size at 40°C
- 15 out of 17 radiators to be replaced (kept 2 towel rads)
- Heat pump oversized for extreme outside temperatures and faster DHW
Where to put the external heat pump unit?

- Maintain 1m distance from property boundary & no impact on external appearance (permitted development rules)
- Minimise potential noise nuisance (MCS design check)
- Minimise external pipe run lengths
- Proximity to consumer unit
- If possible, connect to existing primary pipework
- Close to drain connection
- Maintain air circulation around HP unit
- Secure location
- Avoid blocking access
Final quotation

- Heat loss assumptions updated using survey data
- Latest S40 version of controller (+ £500)
- Cost of radiators included (~£2k)
- Lower design flow temp (40°C) with increased SCOP (3.85)
- DNO grid connection check when accepted
# The EPCs

**Original full SAP OCEPC 2011 : C (80)**

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Current performance</th>
<th>Energy Efficiency</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>Average thermal transmittance 0.35 W/m²K</td>
<td>★★☆☆☆</td>
<td>★★★★☆</td>
<td>★★★☆☆</td>
</tr>
<tr>
<td>Roof</td>
<td>Average thermal transmittance 0.15 W/m²K</td>
<td>★★★★★</td>
<td>★★★★★</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Floor</td>
<td>Average thermal transmittance 0.02 W/m²K</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
</tr>
<tr>
<td>Windows</td>
<td>High performance glazing</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
</tr>
<tr>
<td>Main heating</td>
<td>Boiler and radiators, mains gas</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
</tr>
<tr>
<td>Main heating controls</td>
<td>Time and temperature zone control</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
</tr>
<tr>
<td>Secondary heating</td>
<td>Room heaters, electric</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hot water</td>
<td>From main system, plus solar</td>
<td>★★☆☆☆</td>
<td>★★☆☆☆</td>
<td>★☆☆☆☆</td>
</tr>
<tr>
<td>Lighting</td>
<td>Low energy lighting in 29% of fixed outlets</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
</tr>
<tr>
<td>Air tightness</td>
<td>Air permeability 0.0 m³/h.m² (assessed average)</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
<td>★★★★☆</td>
</tr>
</tbody>
</table>

**Current energy efficiency rating:** C (80)

## Recommendations

1. Low energy lighting for all fixed outlets: £43
2. Solar photovoltaic panels, 2.5 kWp: £11,000 - £20,000

**New rdSAP EPC 2020: B (89) (before heat pump)**

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Energy Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>Cavity wall, as built, insulated (assumed)</td>
<td>★★★★☆</td>
</tr>
<tr>
<td>Roof</td>
<td>Pitched, 400+ mm loft insulation</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Floor</td>
<td>Solid, insulated (assumed)</td>
<td>-</td>
</tr>
<tr>
<td>Windows</td>
<td>Fully double glazed</td>
<td>-</td>
</tr>
<tr>
<td>Main heating</td>
<td>Boiler and radiators, mains gas</td>
<td>-</td>
</tr>
<tr>
<td>Main heating controls</td>
<td>Programmer, room thermostat and TRVs</td>
<td>-</td>
</tr>
<tr>
<td>Secondary heating</td>
<td>None</td>
<td>-</td>
</tr>
<tr>
<td>Hot water</td>
<td>From main system</td>
<td>-</td>
</tr>
<tr>
<td>Lighting</td>
<td>Low energy lighting in all fixed outlets</td>
<td>-</td>
</tr>
</tbody>
</table>

**Heat demand**

<table>
<thead>
<tr>
<th>Existing dwelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating (kWh per year)</td>
</tr>
<tr>
<td>Water heating (kWh per year)</td>
</tr>
</tbody>
</table>

**Recommended measures**

1. Solar water heating: £4,000 - £6,000
2. Wind turbine: £15,000 - £25,000

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Installation

Day 0

Day 1

Day 2

Day 4

Day 5

Now
Installation

Day 0

Day 1

Day 2

Day 3

Day 4

Day 5
Radiators

A living room radiator before
(K1 400x600)
418W at 75/65/20
87W at 40/32/21

After
(K2 700x1600)
3.4kW at 75/65/20
702W at 40/32/21
Commissioning issues

- Circulation pump not responding to HP controller signal (always running at max power = 55W)
- HP controller replaced with new
- Hot water cylinder thermostat failed after 3 days
- Thermostat replaced
Hidden horrors

Original pipe penetrations made with hammer

Un-insulated primary pipework

No mixer valve for hot water draw off

Over-sized hole for duct

Over-temperature stat not linked to boiler input
Final installed system

- NIBE F2040 8kW monobloc heat pump
- Spirovent strainer & air separator
- Sontex Superstatic 449 heat meter
- Grundfos/NIBE UPM2K 25-70 variable speed pump
- NIBE SMO S40 controller
- NIBE UKV 40L buffer vessel
- NIBE 300L HA-WH5-FS twin coil cylinder
- Expansion vessels

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System schematic

- Heat pump
- Buffer
- Cylinder
- Solar thermal panel
- Radiators

Heat Pump Controls
Solar Controls
Diverter Controls
Radiator Controls
What's inside the casing?

- Fan
- Electronic expansion valve
- 4-way reversing valve
- Inverter controls
- Evaporator multi-channel finned pipe HX
- Variable speed DC fan motor
- Condenser plate HX
- Twin rotary compressor

Source: NIBE F2040 Installer Manual
Monitoring

emonPi

myUplink

3.1.8.1 Heat pump 1

Heat pump F2040/AMS-8
Compressor 8
Charge pump Grundfos UPM2 25-70
Charge pump speed 75%
Time to compressor start Operate
Current compressor frequency 44 Hz
Requested compressor freq 44 Hz
Supply temperature (BT12) 29.2 °C
Return temperature (BT3) 24.7 °C
Discharge (BT14) 58.6 °C
Suction gas (BT17) 4.7 °C
Outdoor temperature (BT28) 1.6 °C
Liquid line (BT15) 27.6 °C
Evaporator (BT16) -3.5 °C
Evaporator (BT16 2) -1.6 °C
Pressure (BP4) 16.9 bar
Low pressure (BP8) 6.0 bar
Handover pack

- Manuals
- Compliance certificate
- MCS certificate
- Benchmark form
- Heat loss calculations
MCS issues:

MCS calculator error

- Error in MCS sheets in handover pack
- Ceiling temperature difference cell uses inside-outdoor temp instead of room-room
- Could have had smaller radiators/HP unit or lower flow temp for RHI payments (+£21/a)

MCS certificate error

- First certificate had incorrect flow temp (45°C) and SCOP (3.54)
- Replacement certificate issued with correct flow temp (40°C) and SCOP (3.85)

<table>
<thead>
<tr>
<th>Spreadsheet Error</th>
<th>Flow Temp ºC</th>
<th>SCOP</th>
<th>Heat Loss kW</th>
<th>Rads kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrected</td>
<td>40</td>
<td>3.85</td>
<td>5.8</td>
<td>6.1</td>
</tr>
<tr>
<td>Corrected</td>
<td>40</td>
<td>3.85</td>
<td>3.1</td>
<td>6.1</td>
</tr>
</tbody>
</table>
Applying for the domestic RHI

- Online application
- Simple form - takes about 10 minutes to complete. Email response from OFGEM the same day
- Input EPC and MCS certificate numbers - system picks up required information (SCOP + heat demand) from the database
- For air source heat pumps payment calculation (tariff 10.85p) =

\[
\text{Heat demand} \times \left( \frac{1}{1 - \frac{1}{\text{SPP}}} \right) \times \left( \frac{\text{tariff rate}}{100} \right) = \text{quarterly payment}
\]
Controls

- Heating curve: set at 35°C flow temp at 0°C external temp + flow temp adjustment based on internal temp setpoint vs. actual internal temp
- Compressor inverter control (350-3500W) to maintain calculated flow temp
- Degree minute control: Actual flow temp – calculated flow temp, -60 DM compressor on, 0 DM compressor off
- 20 timed schedules (heating curve offset/internal temp set point, DHW off, compressor block on/off)
- DHW temperature & DHW vs. Heating priority (% time)
Compressor behaviour

Warm winter day

Cold winter day
Frosting and defrosting

Evaporator ices up at low temperature (<5°C) + high RH
Automatic reverse cycle defrost
4-way valve redirects flow from compressor
Heat from house used to defrost evaporator
~15 Wh electric per defrost lasting 1-2 minutes
Frost build-up affects COP
Expected Heat Pump Efficiency?

MCS SCOP at 35°C = 4.13 (space heat only)
BRE DAHPSE SPFH4 at 35°C = 3.47 (space & DHW)

MCS SCOP at 35°C = 4.13
BRE DAHPSE SPFH4 at 35°C = 3.47

Median = 2.65
Mean = 2.64
n = 292

Bench COP for 35°C flow at 0°C external temp = 3.3

Source: NIBE F2040 Installer Manual

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Measured Heat Pump Efficiency

<table>
<thead>
<tr>
<th>Month</th>
<th>SPFH2</th>
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</thead>
<tbody>
<tr>
<td>Oct-20</td>
<td>4.89</td>
</tr>
<tr>
<td>Nov-20</td>
<td>4.53</td>
</tr>
<tr>
<td>Dec-20</td>
<td>3.93</td>
</tr>
<tr>
<td>Jan-21</td>
<td>3.74</td>
</tr>
<tr>
<td>Feb-21</td>
<td>3.91</td>
</tr>
<tr>
<td>Oct-Feb</td>
<td>4.02</td>
</tr>
</tbody>
</table>

SPFH2 at 0°C external temp = 3.3
Heat transfer coefficient

- HTC calculated using UCL SMETER multiple linear regression method
- Used daily heat meter and electricity data plus internal temperatures (6 locations), external temperature and vertical south solar insolation
- Adjustments for DHW use, cylinder gains and estimated metabolic gains

**SMETER HTC = 195 W/K +/- 3**

<table>
<thead>
<tr>
<th></th>
<th>Design delta-T (K)</th>
<th>Design Heat Loss (kW)</th>
<th>HTC (W/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installer MCS calculator</td>
<td>23</td>
<td>5.8</td>
<td>252</td>
</tr>
<tr>
<td>Installer MCS calculator corrected temperature</td>
<td>23</td>
<td>3.1</td>
<td>135</td>
</tr>
<tr>
<td>Installer MCS calculator other inputs corrected</td>
<td>23</td>
<td>4.0</td>
<td>174</td>
</tr>
<tr>
<td>Fabric U-values, thermal bridging, measured airtightness + estimate of extra ventilation</td>
<td>23</td>
<td>4.3 to 4.5</td>
<td>187 to 197</td>
</tr>
</tbody>
</table>
### Comfort taking

#### Living Room Daily Mean Temperature Oct-Jan (2019/20 with gas boiler, 2020/21 with air source heat pump)

<table>
<thead>
<tr>
<th></th>
<th>Mean Living Room Temp °C</th>
<th>SD Living Room</th>
<th>Mean Bedroom Temp °C</th>
<th>SD Bedroom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct 19-Jan 20 (Gas Boiler)</td>
<td>17.17</td>
<td>0.71</td>
<td>18.23</td>
<td>0.78</td>
</tr>
<tr>
<td>Oct 20-Jan 21 (ASHP)</td>
<td>19.81</td>
<td>0.50</td>
<td>20.34</td>
<td>0.46</td>
</tr>
<tr>
<td>Difference</td>
<td>2.65</td>
<td>-0.20</td>
<td>2.11</td>
<td>-0.32</td>
</tr>
</tbody>
</table>

#### Bedroom Daily Mean Temperature Oct-Jan (2019/20 with gas boiler, 2020/21 with air source heat pump)
Thermal comfort

• Lower radiant heat from radiators with ASHP noticeable – but not uncomfortable
• Temperature feels more even with ASHP – over day, room-to-room and stratification
• Overnight temperature in bedroom higher than used to – difficult to reduce - getting used to it
• House is now warm and welcoming all the time especially when coming in from the cold
• Don’t really have to think about heating anymore
Energy consumption

Postcode level data:
~3,500 kWh electric import
~10,500 kWh gas import
Net: 14,000 kWh

Prediction for 2021:
~3,100 kWh electric import
~120 kWh gas import
~2,000 kWh electric export
Net: 1,220 kWh (~200kg CO₂)

2012/13:
~2,500 kWh electric import
~11,000 kWh gas import
Net: 13,500 kWh

2015-19:
~1,100 kWh electric import
~6,900 kWh gas import
~3,000 kWh electric export
Net: 5,000 kWh
## Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat pump</td>
<td>£9,534</td>
</tr>
<tr>
<td>Radiators</td>
<td>£2,011</td>
</tr>
<tr>
<td>Heat meter</td>
<td>£520</td>
</tr>
<tr>
<td>EPC</td>
<td>£50</td>
</tr>
<tr>
<td>Stone chippings</td>
<td>£15</td>
</tr>
<tr>
<td>New fence post</td>
<td>£30</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>£12,160</strong></td>
</tr>
<tr>
<td>Annual RHI</td>
<td>£885</td>
</tr>
<tr>
<td><strong>TOTAL (7 Years)</strong></td>
<td><strong>£6,196</strong></td>
</tr>
</tbody>
</table>

### Energy Consumption

<table>
<thead>
<tr>
<th></th>
<th>Boiler* kWh/a</th>
<th>ASHP kWh/a</th>
<th>Boiler £/a</th>
<th>ASHP £/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric</td>
<td>1100</td>
<td>3000</td>
<td>£256</td>
<td>£561</td>
</tr>
<tr>
<td>Gas</td>
<td>11000</td>
<td>120</td>
<td>£357</td>
<td>£68</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>12100</strong></td>
<td><strong>3120</strong></td>
<td><strong>£613</strong></td>
<td><strong>£629</strong></td>
</tr>
</tbody>
</table>

Octopus 12 month fixed tariff: Gas 2.66 p/kWh £65/a SC, Electric 16.07 p/kWh £79/a SC

* Estimated boiler/electric consumption with PV and 20degC internal set point
Some observations based on my experience

For householders

- Heat pumps are complicated: householders will need support to use them effectively
- The options are overwhelming: need for simple-to-use tools to make informed decisions

Design & installation issues

- Large radiators/UFH needed for optimal efficiency: impacts on a home will vary
- Lots of HP manufacturers but limited choice of qualified and experienced installers
- Monitoring data is key to achieving best performance

Policy issues

- There are problems with underlying processes such as MCS and EPCs
- To boost heat pump uptake base EPC recommendations on whole life cost and emissions
- High cost of electricity compared to gas is disincentive to switch to heat pumps
What next?

- Consider replacing gas hob with induction hob to go “all electric”
- When all electric, investigate options for gas supply disconnection – would save on gas service charge but might be costly to carry out
- When existing SMETS1 meter upgraded to DCC investigate suitable time of use tariffs (e.g. Octopus Agile) which could save on annual electricity costs
- Move room temperature sensor from landing to more representative location
- Investigate cost effective fabric measures
- Try out some different heat pump control strategies – e.g. control using heating curve only
And finally – the heat pump gets the feline seal of approval

Misty says: “Heat pumps are hot stuff!”