A Review of Domestic Heat Pump Coefficient of Performance

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In order to characterise the performance of domestic air and ground source heat pumps (ASHP and GSHP), the Coefficient of Performance (COP) from over 100 models was collected, along with the temperature rise across the heat pump. Domestic scale heat pumps were loosely defined to have a thermal output of 20kW or less, ideally using single phase supply under 250V. No distinction was made between products for space heating, water heating or both.

The temperature rise was taken to be the different between the outlet water temperature for space heating or domestic hot water and the ambient temperature at the cold heat exchanger. For ASHP this was ambient air temperature (dry bulb, if specified). For GSHP, the temperature of the cold heat exchanger itself was sometimes specified, implying that either the ground temperature or the entry temperature of the refrigerant into the compressor was used. These cases were treated as-is, and temperatures were not corrected for.

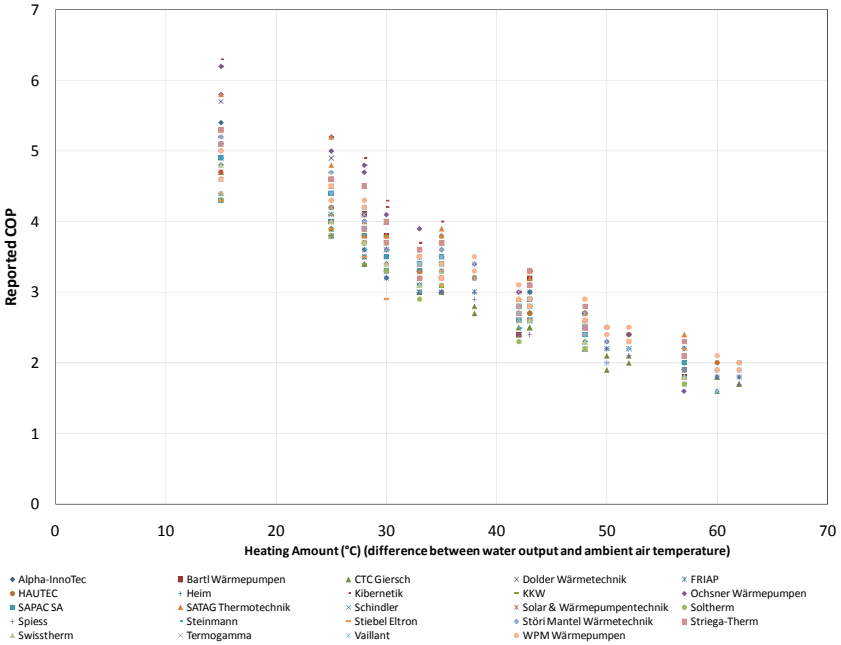
From the relationship between COP and temperature rise, the annual seasonal performance in the UK was estimated. COPs for ASHP and GSHP operating in the UK are calculated, with output temperatures ranging from 30 to 60°C. These are compared to published results from independent tests and field trials.

Manufacturer's data

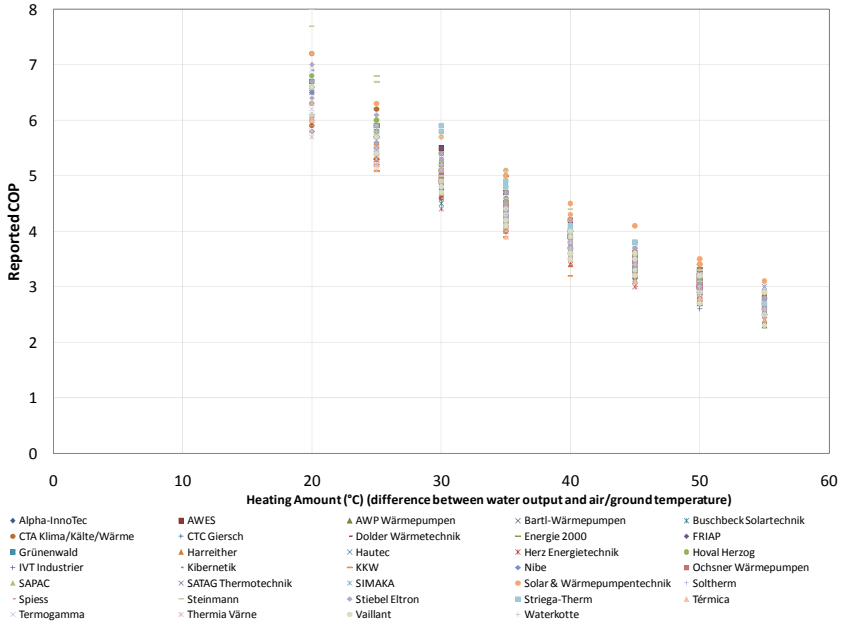
Data collated by NTB

A wealth of information was available from the Wärmepumpen-Testzentrum (WPZ) for both air source and water source heat pumps.[1] Data was collected from their PDF datasheets during July 2008, and is summarised in graphical form to save reproducing several pages worth of tables.

Data from ASHP manufacturers: [2]



Data from GSHP manufacturers: [2, 3]



ASHP Data from other manufacturers

Data from manufacturer's product data sheets are presented below. When a data sheet gave information for several models of different capacities, only one is presented unless they showed markedly different COP values, or were tested at different temperature combinations. These data are presented in the following standard form:

	..	Outlet Temperature	(°C)
..	..	..	..
Ambient Temperature	..	COP values	..
(°C)	..	..	..

Nibe Fighter 2005-8: [4, 5]

	35	45	50
-7		2.41	2.22
0		2.86	
2	3.63		2.72
7	3.95	3.35	3.13
15			3.76

Calorex AW4500: [6]

	35	55
0	3.05	1.93
7	3.73	
20	4.60	3.43

Ciat Aqualis 60 H (top) and 60 HT (bottom): [7][1]

	35	45
7	3.64	3.18
7	4.14	3.48

Thermia Atria Model 6 (top) and 8 (bottom): [8] *(3 phase 400V)*

	35	50
7	3.4	2.4
7	3.8	2.7

Daikin Altatherma ERHQ008AD (top) and ERHQ006AD (bottom):[2]

	35	45
7	4.05	3.00
7	4.56	3.18

Hitachi AquaFREE: [9]

	35	35
7	3.46	4.05

IVT Optima 600 (top) and 800 (bottom): [10] *(3 phase, 400V)*

	35	45
7	3.93	3
7	3.6	3

[1] Was originally available from http://www.ciat.co.uk/downloads/NA07623A_Aqualis.pdf (July 2008)

[2] Was originally available from http://www.daikin.co.uk/airconditioning-products/altherma/system/erhq.jsp (July 2008). Data for 7/35°C available from http://www.altherma.eu/binaries/EPC08-720A_2_tcm263-92633.pdf as of Jan 2009.

Viessmann Vitocal 300 AW106: [11]

	35	45	55
-14	2.18	1.81	
-7	2.64	2.16	1.76
2	3.23	2.61	2.14
7	3.76	3.06	2.52
10	4.65	3.71	3.01
15	5.00	3.99	3.17

Viessmann Vitocal 350 AW110: [11]

	35	45	55
-14	2.31	1.87	
-7	2.75	2.23	1.87
2	3.32	2.70	2.27
7	3.92	3.19	2.67
10	4.94	3.95	3.24
15	5.23	4.15	3.40

Worcester Bosch Greensource 7kW (left) and 9kW (right):[3]

	35	45
-7	2.3	
2	3	
7	3.4	2.8

	35	45
-7	2.5	
2	3.3	
7	3.8	3

The BRE were commissioned by Mitsubishi to test their 8.5kW EcoDan model to the BS-EN-14511 requirements.[4] The COP was measured at a range of input temperatures, for space heating at three output temperatures, and heating a 180L hot water tank to 55°C. The seasonal COP in the UK was estimated to be 3.6 for space heating (35°C output) and 3.2 for water heating (55°C), giving a representative overall COP of 3.45. See page 17 of [12] for more details. Note that the water heating COP values are substantially higher, as variable temperature output is used by the EcoDan controller.

For space heating:

	35	45	55
-5	2.75	2.22	1.67
2	3.23	2.61	2.12
7	4.27	3.49	2.56
12	4.89	3.58	2.71

For water heating:

	55
-5	2.03
2	2.70
7	3.16
12	3.63
20	4.23
25	4.87

[3] http://www.worcester-bosch.co.uk/homeowner/literature/air-source-heat-pumps-literature

[4] In calculating COP values to this standard, all parasitic loads of the heat pump are included *(the compressor and all pumps).*

GSHP Data from other manufacturers

Nibe Fighter 1140 / 1240: [13]

	35
0	4.6

Calorex 3500: [6]

	35	55
0	4.53	3.68
15	6.08	4.76

Ciat Aureu Caleo 50: [14]

	45
10	5.1

Thermia Diplomat TWS Model 6 (top) and Model 8 (bottom): [15] *(3 phase, 400V)*

	35	50
0	4.2	3.1
0	4.6	3.4

Nordic Geothermal WEC-68-HW: [16] *Advertised as "Up to 694% efficient"...*

	35	50
0	4.23	3.18
6	5.37	3.82
10	6.49	4.57
12	6.94	4.87

IVT Greenline HT Plus C/E 6 (top) and C/E 11 (bottom): [17] *(3 phase, 400V)*

	35	50
0	4.54	3.18
0	5.02	3.48

Viessmann Vitocal 300 BW/WW 106 (left) and 113 (right): [11]

	35	45	55
0	4.57		
2		3.76	2.95
8		4.11	3.24
10	5.60		
-5	4.00	3.14	2.53
15	6.05	4.52	3.53

	35	45	55
0	4.59		
2		3.84	3.05
8		4.34	3.43
10	5.90		
-5	4.02	3.19	2.61
14	6.45	4.83	3.78

Viessmann Vitocal 350 BW/WW 110 (left) and 113 (right): [11]

	35	55	65
0	4.31		
2		3.14	2.59
8		3.39	2.83
10	5.22		

	35	55	65
0	4.32		
2		3.11	2.49
8		3.37	2.68
10	5.18		

Worcester Bosch Greenstore 6 (top) and 11 (bottom):[5] [18]

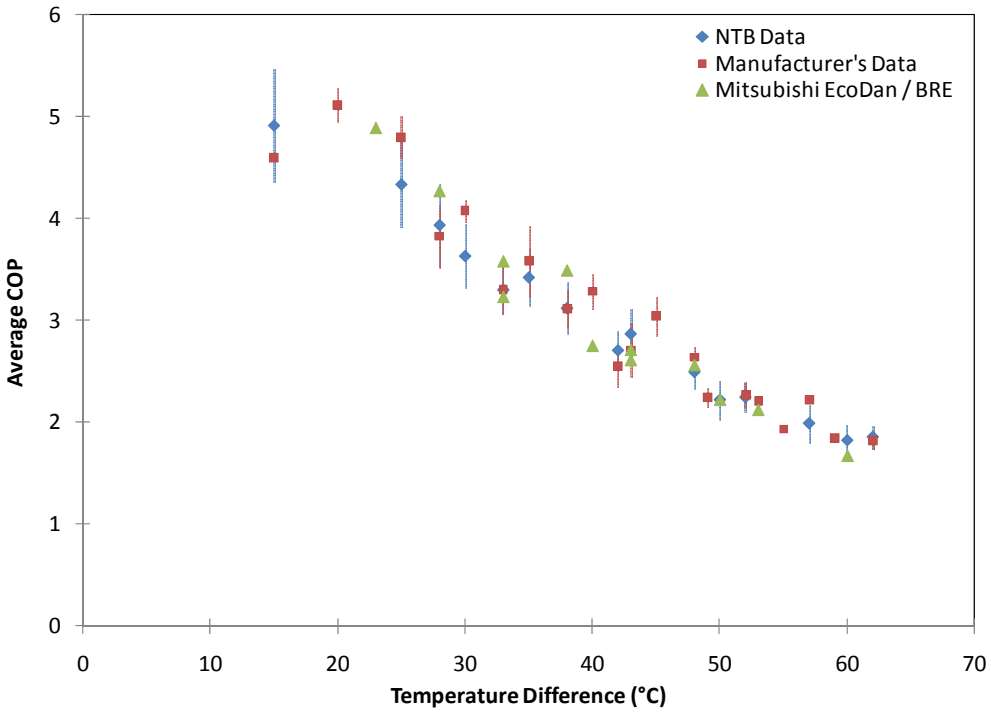
	35	50
0	3.8	2.8
0	4.6	3.2

[5] http://www.worcester-bosch.co.uk/homeowner/literature/ground-source-heat-pump-literature

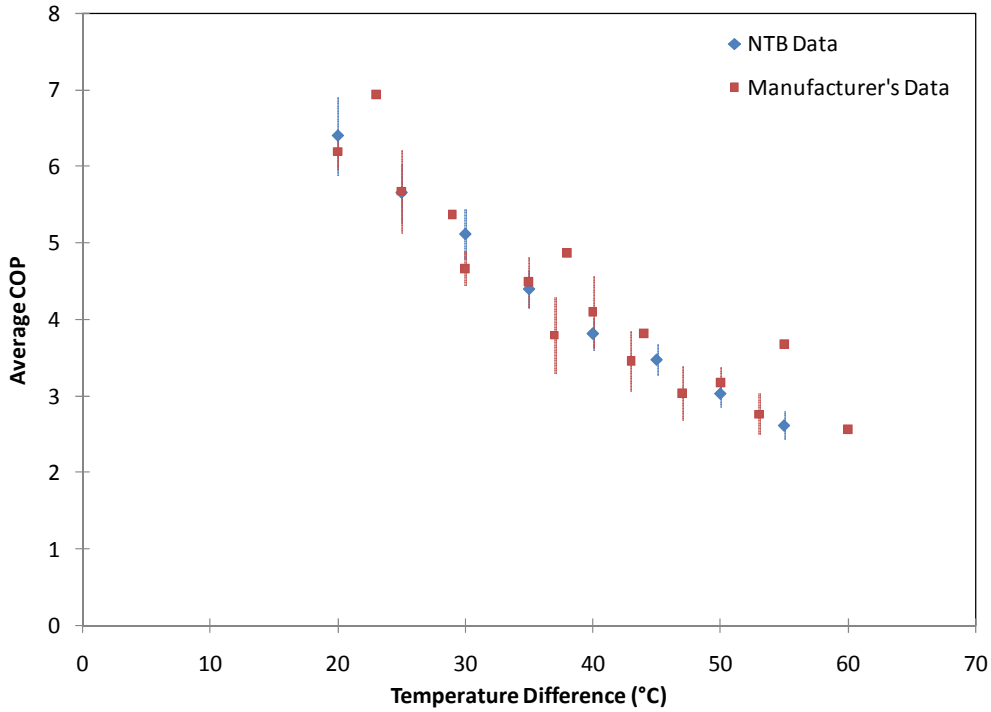
Summary of data

All the data points were grouped by their temperature difference (outlet – ambient) and the averages plotted. The NTB data were plotted against all of the sources found, with bars to represent ± 1 standard deviation in values at each temperature difference. Agreement between sources in both cases appears to be satisfactory. Linear fits to each data set suggest that COP falls by 0.67-1.07 for every 10°C temperature rise.

ASHP average COPs against temperature difference:



GSHP average COPs against temperature difference:



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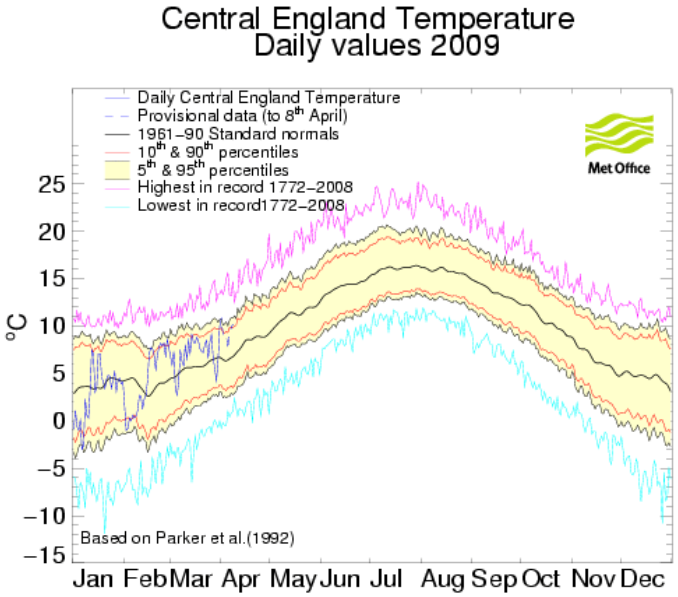
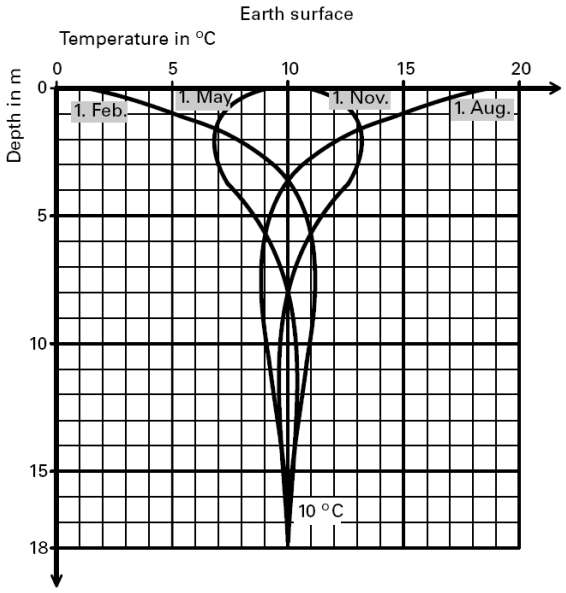
Estimating Annual Seasonal COP in the UK

To estimate the average COP that would be experienced in practical usage, both the external temperature (air or ground) and the internal temperature (hot water output) must be known. Seasonal temperatures in the UK are well recorded, however the heat distribution temperature is chosen on an individual basis by the heat pump's manufacturer or the user. Expected COPs are therefore presented for a set of outlet temperatures, ranging from 30°C for underfloor heating, through 45°C for conventional radiators (run relatively cool) to 60°C for providing potable hot water or high temperature space heating.

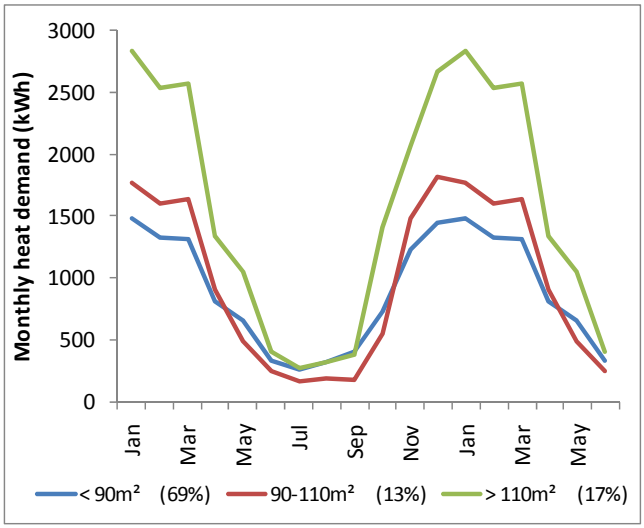
The annual air temperature in the UK has been recorded since the late 18th century, and monthly averages range from 4°C in winter to 16°C in summer.[19] Underground temperatures rapidly converge towards the annual average temperature as depth increases.[20] Even at the shallow depths that horizontal ground-loops are installed (~2m), ground temperatures converge to 7-13°C.

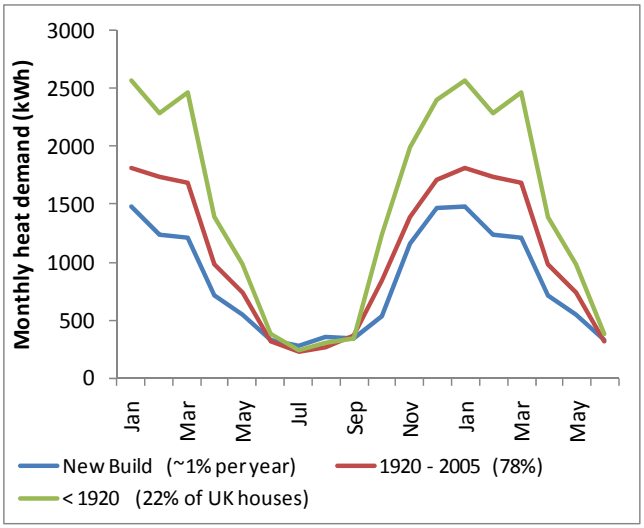




Reproduced from [19, 20]

Demand for heat is mostly during winter, when air temperatures are at their coldest – hence ASHP performance suffers. The monthly distribution of heating demand in UK houses was measured in a set of 90 houses over a period of ~2 years by the Carbon Trust.[21] The distribution, broken down into building size and age is as follows:





The monthly average UK temperature can therefore be weighted by the average heat demand in each month – giving the average external temperature that heat pumps would operate with:

Month	Ground Temperature	Air Temperature			Relative portion of heating demand
		Coldest 10%	Average	Hottest 10%	
January	9.7	-1	4	8	181%
February	8.0	-1	4	8	166%
March	7.7	2	6	9	166%
April	7.3	5	8	11	96%
May	7.0	8	12	14	72%
June	8.7	10.5	14	18	32%
July	10.3	13.5	16	19	24%
August	12.0	13	16	19	28%
September	12.3	11	13.5	16.5	36%
October	12.7	7.5	10.5	13.5	84%
November	13.0	2.5	7	10.5	142%
December	11.3	0	4	8.5	173%
Average	10.0	5.9	9.6	12.9	
Weighted	9.8	2.8	6.9	10.4	

The average annual COP expected in the UK can be calculated from the weighted average temperatures, which accounts for the majority of space heating occurring during winter. These COPs were taken from the spread in observed COPs presented in the previous charts, over the given temperature ranges:

Outlet Temperature	ASHP		GSHP	
	Temperature Difference	Average COP	Temperature Difference	Average COP
30°C	19-27°C	4.1-4.9	17-23°C	5.6-6.6
40°C	29-37°C	3.3-3.9	27-33°C	4.5-5.4
50°C	39-47°C	2.5-3.1	37-43°C	3.5-4.2
60°C	49-57°C	2.0-2.4	47-53°C	2.8-3.4

Data from Real World Field Trials

These predicted average annual COP values can be compared to the following results gathered from field trials of domestic heat pump systems. Note that the COP values presented in the previous table are for the heat pump only – and do not take into account any additional energy used on the backup heater (usually a resistance immersion heater – with COP = 1). In a carefully sized system, use of the immersion heater can be minimised to only provide 3-6% of the supplied heat.[22, 23] With a heat pump of COP = 4.0, this would reduce the overall system performance to between 3.82 and 3.91.[6]

ASHP: Slovenia, 1995 [24]

A 12kW unnamed ASHP was installed in a Slovenian house in 1995, with a central European climate averaging 7°C. It was operated for 9 years, producing water for space heating at 45°C (35°C return temperature) with an average COP of **3.16**. Annual and monthly average COPs were presented in Figures 4 and 5. A linear least-squares fit between the temperature and COP data-pairs gives the following extrapolation:

	45
0	2.89
5	3.16
10	3.43

[6] 3.82 = (0.94 * 4)+(0.06 * 1)

GSHP: Slovenia, 1995 [24]

Six unnamed GSHPs of unknown size were installed in other houses, utilising ground water at an average of 9°C. The annual average COP was **3.4**, with a minimum of 3.18 during Winter months, when the ground water temperature was 5°C. Only two COP values were given, for the annual average and during Winter months.

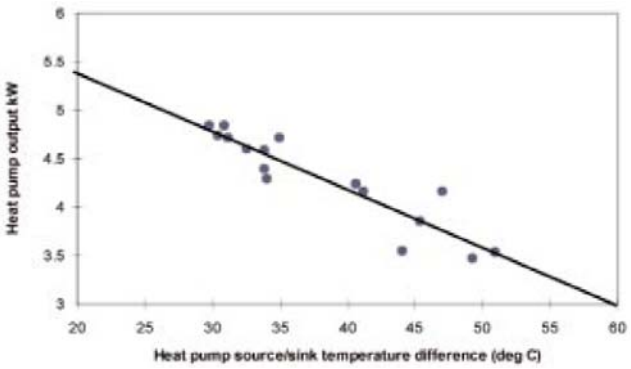
GSHP: UK, 1998 [25]

An IVT Greenline 4 was installed with two 2kW immersion heaters in a large detached home in the UK, and monitored for around one year. Outlet temperatures were 45°C for under-floor space heating, and 50°C for hot water. The COP of this system was limited by the choices made during installation.

COP of the heat pump was **3.16** during this time, but was reduced significantly due to a circulation pump set to run continuously. If this pump ran only when the heat pump was when the heat pump was operating, the COP was estimated to be **3.43**.

The heat pump was sized to only provide 50% of the annual heating demand, so usage of the low-efficiency immersion heaters was significant. These consumed 2.8MWh of electricity, compared to 5.0MWh from the heat pump itself – reducing the overall system's performance factor to **2.39**. This would have increased to **2.52** if the circulation pump was optimised.

The monthly COP was not seen to vary between summer and winter, as summer demand was mostly for higher temperature hot water.



Reproduced from [25]

ASHP: Belgium, 2006 [22]

The seasonal performance of a Daikin Altherma system was **3.76** from November to April, when providing space heating and hot water. The building was well insulated, and used a mix of under floor heating and radiators. This COP was calculated to including energy consumed by the backup heater for boost heating and defrosting the heat pump (as with the SPF above). It also included heat lost from the water storage tank, as this was located indoors and so also contributed to heating the house.

ASHP: Japan, 2006 [26]

36 "Eco Cute" models of heat pump water heaters (from mixed manufacturers) installed in customers' homes were monitored. When producing hot water at 40°C, the annual average COP was **3.16**.

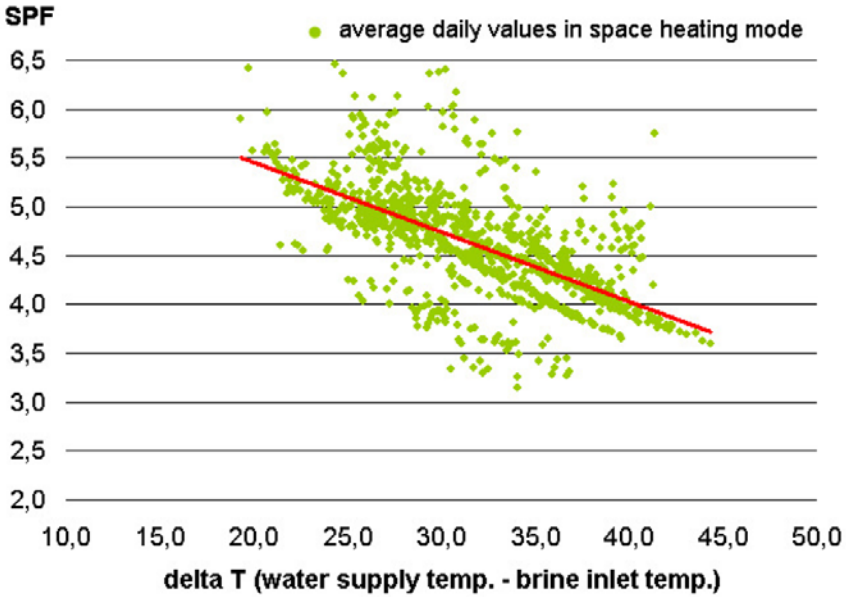
ASHP: Japan , 2006 [27]

A 4.5kW Matsushita "Eco Cute" model (rated COP 4.8) was modelled numerically, and compared with a field test unit. The annual average COP when producing water at 85°C was **3.17**, varying between 2.7 in January and 3.9 in July.

ASHP and GSHP: Germany, 2007 [23]

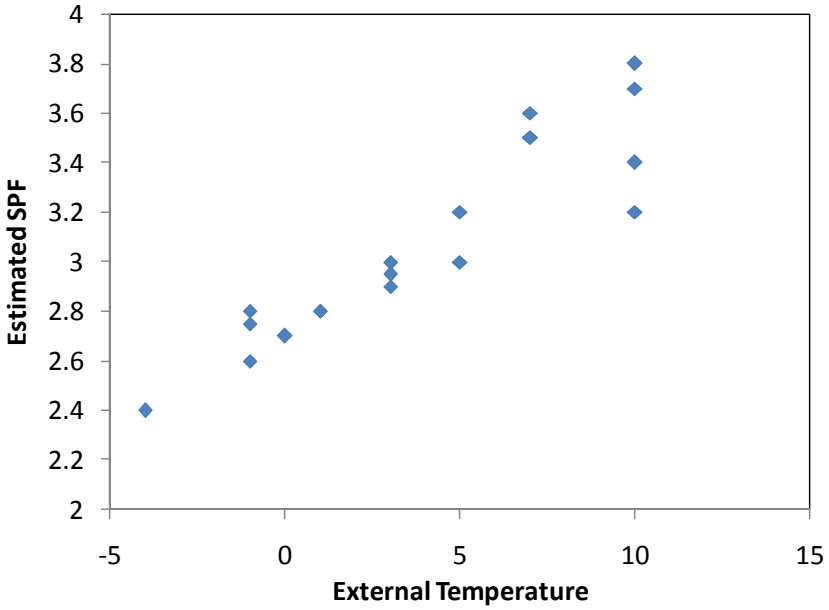
The Fraunhofer Institut as part of their WP-Efficienz project installed over 110 heat pumps from 7 manufacturers throughout Germany and monitored them constantly. The Seasonal Performance Factor (SPF) was calculated, which was the COP for both space and water heating, including any energy required and produced by the backup immersion heater. This gave a more accurate measure of real-world performance, giving (total amount of heat out / total amount of power required)

Over one year, around 40 GSHPs had an average SPF of **3.72**. Plotted against temperature difference, the results were:



Reproduced from [23]

Over one year, around 6 ASHPs had an average SPF of **2.99**. The variation of SPF with temperature has been estimated based on the limited data provided:



It should be noted that the majority of data was collected during winter months, which lowered these preliminary SPF values. Data shall continue being collected until 2010, so the final results will prove more conclusive.

GSHP: Japan, 2007 [28, 29]

A Sunpot Co. 10kW GSHP-1001 was installed in a low energy house in 2007. The COP versus outlet temperature was found to be 2.1 @ 60°C, 3.3 @ 45°C, 4.5 @ 35°C and 5.2 @ 30°C. Ambient and inlet temperatures were not stated. A separate system obtained a COP of 4.0 when space heating with ΔT = 22.6°C, and 2.47 when heating water with ΔT = 62.9°C. The average COP measured between November and May was **4.45**, with outlet temperatures in the range of 30-35°C.

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