# EU-US COMPARISON OF ENERGY EFFICIENCY REQUIREMENTS FOR AIR-SOURCE HEAT PUMPS

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**Abstract:** To be worthy of some kind of financial support, air-source heat pumps in the EU need to be by 50 % more energy efficient than those in the US. The fact that air-source heat pumps are predominantly of air-to-water type in the EU and of air-to-air type in the US, makes European heat pumps of any brand seem more sophisticated than American ones. Detailed analysis was conducted and showed that this discrepancy is merely caused by the application of different calculation methods. Nonetheless, it does not explain away the differences in efficiency resulting from the use of different ASHP types in the EU and in the US.

**Key Words: air-source heat pumps, heating seasonal performance factor**

## 1 INTRODUCTION

To qualify for tax credit or any other kind of subsidization, air-source heat pumps in the EU have to show an energy efficiency that is by 50 % higher than that of heat pumps in the US (HSPF = 3.5 and 8 BTU/kWh = 2.345 kWh/kWh, respectively). The fact, that air-source heat pumps are predominantly of air-to-water type in the EU and of air-to-air type in the US, makes European heat pumps of any brand seem even more elaborated than American ones.

In the paper, we address this discrepancy. It may be caused by different rating or weather conditions, the application of different HSPF calculation procedures as well as by several other key factors, such as:

- operation mode (mono- or bivalent)
- choice of bivalence point (for bivalent operation)
- performance degradation factor (for part load conditions)
- for air-to-water ASHPs:
  - application (underfloor, convector or radiator heating)
  - heating water supply temperature
  - ratio of domestic hot water to heating production (DWP)

How important these issues actually are depends on how they influence the performance results and to what extent they are relevant for typical equipment on the heating market in the respective country.

## 2 EUROPEAN HEAT PUMP MARKET

If not mentioned otherwise, the data on market volumes and values (Table 1) and citations given thereafter are taken from BRG Consult studies on the heating market of European

countries (BRG Consult 2009). Being focused exclusively on the heating market, BRG Consult studies refer to the market of heat pumps dedicated to heating only (i.e. not reversible ones); sales data for VRF/VRV are, unfortunately, not accounted for. In some countries (e.g. UK and Portugal), however, the greatest majority of heat pumps found in the market were reversible ones. Reversible heat pumps used to be covered in BSRIA studies for Central Plant and Packaged Air Conditioning, which were available until 2003.

In this paper, detailed market analysis is limited to France and Germany, for together they account for some 60% of European HP market.

According to BRG, the vast majority of all heat pumps was sold with an output below 20 kW, so mainly for one to two family dwellings. Sales of heat pumps with an output larger than 20 kW remained low with the majority of them being ground-source heat pumps. Further technical segmentation (split/monobloc technology, type of compressor, refrigerant, hydraulic kit, built-in electric heating coil, etc.) is not addressed in the BRG studies. (Such technicalities used to be addressed by the above mentioned BSRIA studies.)

Following observations on the European heat pump (HP) market 2008 (Table 1, Figure 1) seem to be appropriate:

- In terms of HP market value, the European market is clearly led by France (668.6 mil. €), followed by Germany (352.9 mil. €), Sweden (197.3 mil. €), and Switzerland (132.2 mil. €). France became the biggest heat pump market in Europe not earlier than in 2007, following the tax credit plan launched in 2005.
- The HP market volume shows the same pattern: It is led by France (164,000 pieces), followed by Germany (83,700 pieces), Sweden (56,800 pieces), and Switzerland (21,000 pieces).
- Market trends:
  - In France, in 2008 “the market remained largely driven by outside air/water types (+154.9 %), while geothermal products enjoyed a moderate growth... The exceptional boom in sales of outside air/water heat pumps left many manufacturers, and consequently installers, unable to meet demand”.
  - “Following the moderate growth in 2007, the German heat pump market grew strongly in 2008, despite the difficult economic conditions. This development was particularly strong for outside air/water heat pumps”.
- Most heat pumps installed in France and Switzerland are ASHPs of outside air-to-water type (78.7 % and 56.7 %, respectively). On the German market, ground-source HPs and ASHPs (both of water type) are dominating with 50.5 % and 41.7 %, respectively. Sales of air-to-air heat pumps (typical for the US) remain marginal in Europe. It will certainly continue this way for at least several decades, since European dwellings are not built for air ducting.
- The German air-to-water heat pump market is strongly dominated by Stiebel-Eltron with 16,000 pieces sold in 2008, which corresponds to a market share of 51.4 %. In France, there are several key players: Daikin (21,000 pieces, 16.3 %), Aj Tech (16,000 pieces, 12.4 %), Technibel (15,000 pieces, 11.6 %), Ciat (14,000 pieces, 10.9 %), Airmat (12,800 pieces, 9.9 %), and Atlantic (10,900 pieces, 8.4 %).
- Typical for Europe, almost all types of HPs on the French and German market provide for both space heating and hot water production (DHW). The share of “Water Heating only” and “No Hot Water Production” type HPs is maximum 5 % each.
- In Germany, nearly half of all new dwellings have underfloor heating installed. For France no data are given, but its share is supposed to be far less.
- In terms of HPs sold in 2008 per 1000 inhabitants (Table 1), Sweden leads far ahead with 6.24, followed by Switzerland (2.76), France (2.53), Finland (2.40), and Austria (2.20). This is quite amazing; and even more amazing is that 2008 was “a really bad year for heat pumps in Sweden” but “an exceptionally good year for heat pumps in France” and “another successful year” for the Finnish and Austrian market.

- There is no explanation on the technical side for the enormous success of heat pumps in Sweden, Switzerland, Finland, and Austria over countries in the south of Europe. Thus, "soft reasons" like subsidies, incentive schemes, focus on energy efficiency, $CO_2$-footprint awareness and environmental concerns, aggressive marketing and strong advertising campaigns are obviously decisive.
- Judging by BRG data, the UK heat pump market appears quite weak, which might be very misleading. According to BSRIA, Britain is said to be the key European market for VRF/VRV (heat pumps and heat recovery units brought in by Asian, especially Japanese, manufacturers), which, as mentioned before, are not covered by BRG Consult studies.
- Per-capita income
  - A HP market exists in Western European countries only, mostly in countries with a per-capita income of more than $ 30,000 US, with the only exception of the Czech Republic.
  - In Western European countries, neither heat pump sales nor average equipment prices seem to be dependent on per-capita income.
  - Heat pump sales remain marginal in Croatia, Estonia, Hungary, Lithuania, Latvia, Poland, Russia, Turkey, and Ukraine. However, remarkably, almost all heat pumps sold in these countries are of the ground-source type. Probably, given a high degree of social stratification, social classes who can afford a heat pump can afford expensive ground installations as well.

With heat pumps in Europe being almost exclusively of the source-to-water type, it is unfortunate that no data are available on whether they go with a hydraulic kit and supplementary electric heating.

For decades, electric heating has been very popular in France (apparently due to heavy subsidies for electrical power generation) and quite unpopular in Germany. For instance, according to BSRIA, 15 % of the fan coils sold in France and less than 1 % in Germany are equipped with an electric heater (whereby the French fan coil market is at least twice as big as the German one). What is more, according to BRG, dry electric heating in France reached a historical high of more than 71 % of new dwellings in 2007. In Germany, quite on the contrary, this form of heating is used in a few existing dwellings only (3.4 %).

However, the resultant expectation that in Germany, contrary to France[1], ASHPs would not go with built-in supplementary electric heater did not prove true. Seven heat pump brands available on the German market (incl. the dominant market leader Stiebel-Eltron) were examined on the basis of their manufacturer's documentation; six of them were found featuring an electric heater. Thus, the vast majority of European ASHPs is not designed to operate monovalently (with no other heat source than outside air) but bivalently as stand-alone equipment.

## 3 ENERGY EFFICIENCY REQUIREMENTS FOR ASHPs

### 3.1 European Energy Efficiency Requirements

Energy efficiency requirements for ASHPs differ to some extent in the European countries. Even though, they have one feature in common: They call for a rather high Heating Seasonal Performance Factor (HSPF).

[1] That is probably why e.g. Korean HP manufacturers are targeting the French and not the German market in the first place.

**Table 1: European heat pump sales in 2008 by volume and value**

| | | | HP Volume, 000's pieces | | | | | | HP Value, mil. Euro | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | Population mil.(1) | Income per Capita $US | Total 000's pieces | Ground Source | Exhaust Air-Water | Outside Air-Water (ASHP) | HP: Water Heaters | HP per 1000 in-habitants | Total mil. Euro | Ground Source | Exhaust Air-Water | Outside Air-Water (ASHP) | HP: Water Heaters |
| France | 64.8 | $43,990 | 164.0 | 13.1% | 2.7% | 78.7% | 5.5% | 2.53 | 668.6 € | 12.4% | 2.9% | 82.0% | 2.7% |
| Germany | 82.3 | $42,560 | 83.7 | 45.4% | 1.5% | 37.2% | 15.9% | 1.02 | 352.9 € | 50.5% | 2.0% | 41.7% | 5.8% |
| Sweden | 9.1 | $48,930 | 56.8 | 44.9% | 23.2% | 31.9% | 0.0% | 6.24 | 197.3 € | 45.2% | 18.1% | 36.7% | 0.0% |
| Switzerland | 7.6 | $56,370 | 21.0 | 41.5% | 0.0% | 56.7% | 1.8% | 2.76 | 132.2 € | 48.0% | 0.0% | 51.3% | 0.7% |
| Finland | 5.3 | $45,680 | 12.7 | 59.1% | 17.3% | 23.6% | 0.0% | 2.40 | 62.1 € | 60.4% | 14.5% | 25.1% | 0.0% |
| Austria | 8.2 | $46,850 | 18.0 | 54.4% | 8.9% | 12.2% | 24.4% | 2.20 | 62.1 € | 68.5% | 11.6% | 12.2% | 7.7% |
| Netherlands | 16.8 | $49,350 | 10.4 | 54.1% | 0.0% | 33.8% | 12.1% | 0.62 | 53.5 € | 59.4% | 0.0% | 35.6% | 4.9% |
| UK | 62.3 | $41,520 | 7.9 | 66.2% | 1.9% | 31.8% | 0.0% | 0.13 | 38.8 € | 75.7% | 1.0% | 23.4% | 0.0% |
| Norway | 4.7 | $86,440 | 6.8 | 41.2% | 10.3% | 48.5% | 0.0% | 1.45 | 30.8 € | 43.1% | 7.1% | 49.8% | 0.0% |
| Ireland | 4.6 | $44,310 | 3.5 | 55.1% | 1.4% | 43.5% | 0.0% | 0.76 | 22.0 € | 61.8% | 0.7% | 37.5% | 0.0% |
| Denmark | 5.5 | $58,930 | 5.3 | 54.7% | 7.5% | 11.3% | 26.4% | 0.96 | 19.3 € | 57.2% | 7.1% | 16.2% | 19.6% |
| Czech Rep. | 10.2 | $17,310 | 3.8 | 48.5% | 3.1% | 47.9% | 0.5% | 0.37 | 18.0 € | 53.4% | 3.3% | 43.0% | 0.3% |
| Belgium | 10.4 | $45,310 | 3.1 | 35.3% | 0.0% | 54.5% | 10.3% | 0.30 | 16.6 € | 39.1% | 0.0% | 56.2% | 4.6% |
| Italy | 58.1 | $35,080 | 2.7 | 38.7% | 0.0% | 57.8% | 3.5% | 0.05 | 12.9 € | 42.3% | 0.0% | 56.3% | 1.4% |
| Spain | 46.5 | $31,870 | 1.8 | 44.4% | 0.0% | 55.5% | 0.0% | 0.04 | 8.3 € | 57.8% | 0.0% | 42.2% | 0.0% |

(1) Estimation for 2010, http://www.internetworldstats.com/stats4.htm#europe (entered July 2010)

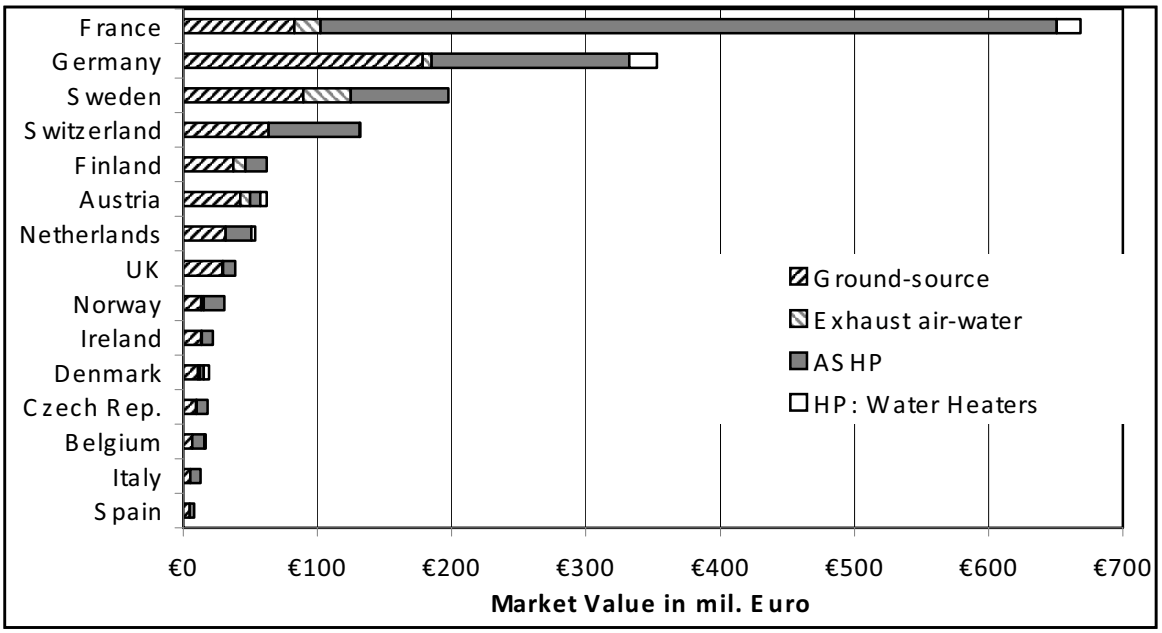



**Figure 1: European heat pump market 2008 by value**

Since 2008, heat pumps in France must reach a HSPF of 3.3 instead of the previous value of 3.0 (BRG 2009), in order to qualify for tax credits.

In Germany, using renewable energy sources is obligatory. That means, from 2010 on, home owners who want to replace their heating system are obliged to cover at least 10 % of their annual heating energy demand by renewable energies (EWärmeG 2009[2]). For new buildings, the share is set to 20 % as of 2009.

In order to meet this obligation, one of the following measures can be taken among others:

- use of an electric heat pump to cover the entire heating demand with a HSPF of 3.5 or
- use of an electric heat pump that does not cover the entire heating demand with a HSPF of 3.5 whereby only the heat which is generated with a HSPF beyond 3.0 qualifies as renewable and is accepted to meet the respective obligation.

According to another regulation, the HSPF of 3.5 refers to heating only; if domestic hot water production is also covered, a HSPF of 3.3 is sufficient. Then again, some other regulations distinguish between newly built and refurbished dwellings with HSPFs of 3.5 and 3.3 respectively.

The first measure refers to monovalent operation, which, as stated before, is not of great relevance, for the vast majority of ASHPs available on the German market nowadays goes with a built-in supplementary electric heater.

The second measure refers to bivalent operation, i.e. supplementary heating equipment is needed beyond the bivalence (or balance) point. The bivalence point is defined to be the point when the heat pump does not manage to meet the heating demand alone at times when the outdoor air temperature drops below it. Bivalent operation can either be bivalent-parallel (both heat pump and supplementary heating equipment operate beyond the bivalence point) or bivalent-alternative (beyond the bivalence point, only the supplementary

[2] http://www.uvm.baden-wuerttemberg.de (entered Dec. 2010)

heater remains operational, the heat pump is switched off). Whenever this supplementary heating equipment is an electric heater, bivalent-parallel operation will beat the other option at any time in all respects – investment and operational costs, as well as conservation of primary energy sources.

However, as stated before, electric heating has never been popular in Germany. This fact makes the second measure (where only the heat which is produced with a HSPF beyond 3.0 qualifies for renewable energy and is accepted to meet the obligation), which calls for bivalent-alternative operation, very German. For it makes sense only when the supplementary heating equipment is a boiler of whatever type, opposed to an electric heater, as it has traditionally been the case in Germany, and probably aims to protect the German boiler market.

These latest regulations are setting quite a high goal, though, rather than reflecting common practice, as various field tests show.

### 3.2 European Field Test Results Versus Energy Efficiency Requirements

Numerous long-term and recently conducted field performance assessment tests in Germany and Switzerland showed that air-to-water type ASHPs achieve a HSPF of "merely" something between 2.0 and 3.0 with an average value of 2.65 (Agenda Group Energy 21[3]).

Two other useful results of these field tests are:
- Using underfloor heating instead of radiators leads to an increase of HSPF by 0.5.
- For almost all hydraulic systems, the HSPF drops by 0.3 if losses in buffer tanks (for both heating and domestic hot water) are considered.

French test results for regions close to the German border are similar (Barbouchi et al. 2010).

Thus, a required HSPF of 3.5 or 3.3 is clearly a long way from the commonly attained values. The question arises whether the required energy efficiency can be achieved at all with the heat pumps available on the market. If not, a new generation of ASHPs would be needed.

### 3.3 EU-US Comparison of Energy Efficiency Requirements

As shown above, European heat pumps have to feature a HSPF of 3.5 or 3.3 to be worthy of some kind of financial support[4,5].

Quite on the contrary, new HPs manufactured in the US after 2005 are required to have a HSPF of at least 7.7 BTU/kWh (2.257 kWh/kWh). The most efficient ones have a HSPF of 10 BTU/kWh (2.931 kWh/kWh). A HSPF ≥ 8 BTU/kWh (2.345 kWh/kWh) is considered high efficiency and worthy of a US Energy Tax Credit[6]. Mini-split Heat Pumps even hold a HSPF ≥ 9 BTU/kWh (2.638 kWh/kWh)[7]. Data for residential equipment are similar[8].

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3 http://www.agenda-energie-lahr.de/WP_VergleichFeldtests.html (entered July 2010)

4 Acc. to BRG 2009: In France, a 15 % tax credit was introduced in 2000, increased to 40 % in 2005 and to 50 % in 2006. In 2009, it was cut back to 40 % and to 25 % in 2010 (40 % tax credit will still apply when installed in recently – within the last two years - acquired dwellings built before 1977).

5 10 % of cost (up to € 1,500) for refurbishment, 10 % (up to € 850) for new build

6 http://www.museumstuff.com/learn/topics/HSPF (entered July 2010)

7 http://www.sipshousepdx.com/?p=250 (entered July 2010)
Tax Credit for home owners: 30 % of cost up to $ 1,500 (expires Dec. 2010)

8 US Federal Tax Credits for Consumer Energy Efficiency / Requirements for ASHPs:
*Split Systems:* HSPF ≥ 8.5, EER ≥ 12.5, SEER ≥ 15

All in all, to be worthy of a tax credit, US ASHPs need to have a HSPF of 2.345. Given that ASHPs in the EU are of the air-to-water type and in the US of the air-to-air type, European energy efficiency requirements seem to be by more than 50 % higher than the American ones.

However, HSPF values might be calculated on a different basis and therefore not be comparable:

- Discrepancies may be caused by different rating or weather conditions, or different HSPF calculation procedures.
- In the US, the seasonal performance factor is commonly listed by the manufacturers (in fact, for both cooling and heating, which is SEER and HSPF, respectively) for Region IV (the most populated areas). It is calculated acc. to AHRI 240/210:2008.
- In Europe, this value is not given by the manufacturers and has to be provided by the HVAC engineer for each particular project. It is calculated acc. to VDI 4650-1:2009.

### 3.4 EU-US Comparison of ASHP Rating Conditions

The rating conditions are listed below for both cooling and heating, since most European and certainly all American heat pumps are reversible. In the first step, the conditions for air-to-air heat pumps in the EU and the US were compared (EN 14511-2:2004/2007 and AHRI 210/240:2008, respectively). Measurements are done at steady-state conditions.

In Europe, the standard rating conditions for air-to-air heat pumps are set as follows:

- For cooling:
  - Standard condition: Outdoor dry / wet bulb = 35.0°C / 24°C
  - Application condition: Outdoor dry / wet bulb = 27.0°C / 19°C
  - Air entering Indoor Unit is of dry / wet bulb = 27°C /19°C
- For heating:
  - Standard condition: Outdoor dry / wet bulb = 7°C / 6°C
  - Application condition:
    - Outdoor dry / wet bulb = 2°C / 1°C
    - Outdoor dry / wet bulb = -7°C / -8°C
    - Outdoor dry / wet bulb = -15°C / (no data)
  - Air entering Indoor Unit is of dry / wet bulb = 20°C /15°C (max.)

The EU-US comparison showed that the standard rating conditions for air-to-air heat pumps in the EU and the US are almost identical and cover at least the heating capacity range relevant to this paper (under 20 kW). This also applies to the fact that for cooling, performance for almost the hottest day of a cooling season is given as standard, whereas for heating, the standard performance refers to a very mild day. As a result, mean seasonal values for cooling are bound to be higher than those at standard test conditions (part-load conditions), whereas for heating they are always smaller.

For the same duty, air-to-water heat pumps must use more energy than air-to-air heat pumps (because an additional water-to-air heat exchanger on the consumer side is deployed). The figures for European air-to-air units in contrast to European air-to-water units are:

- For cooling:
  - Air-to-air: Air entering Indoor Unit is of dry / wet bulb = 27°C /19°C
  - Air-to-water: Water inlet / outlet = 23°C / 18°C
- For heating:
  - Air-to-air: Air entering Indoor Unit is of dry / wet bulb = 20°C /15°C (max.)

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*Packaged systems:* HSPF ≥ 8, EER ≥ 12, SEER ≥ 14
http://www.energystar.gov/index.cfm?c=tax_credits.tx_index (entered July 2010)

- Air-to-water: Water inlet / outlet = 35°C / 30°C

The comparison shows that the test conditions for air-to-water ASHPs are more severe than for air-to-air units, especially for heating:

- At standard rating conditions for cooling (outdoor dry bulb 35°C), the median temperature difference between outdoor air and indoor coil is 12 K for air-to-air and 14.4 K for air-to-water (factor 1.21).
- At standard rating conditions for heating (outdoor dry bulb 7°C), the median temperature difference between outdoor air and indoor coil is 10.5 K for air-to-air and 25.5 K for air-to-water (factor 2.43).

Thus, the different requirements for ASHPs in the EU and the US cannot be explained with differences in rating conditions.

### 3.5 Weather Conditions

In order to keep the following analysis concise, it was limited to Region IV in the US and Midwest Germany (close to the French border) exemplarily for Europe.

It is obvious that, just due to their geographic positions, it is cooling that counts most in the US, whereas heating is decisive in Germany. However, design temperatures are more severe in the US (Table 2). Not less surprisingly, the ratios of heating to cooling hours differ by far more than expected, being 2.8 and around 10, respectively.

**Table 2: Weather conditions**

| Location | Frankfurt/Main, Germany | JFK Airport, NY, USA Region IV |
|---|---|---|
| Outdoor air design temperature for heating | -10°C | 5°F (-15.0°C) (AHRI 240/210) |
| Annual extreme daily temp. (ASHRAE Fundamentals)<br>- Min<br>- Max | <br><br>34.1°C<br>-12.1°C | <br><br>35.3°C<br>-14.7°C |
| Heating Load Hours (HLH)<br>Cooling Load Hours (CLH)<br>Ratio HLH/CLH | no data available | 2,250 h (AHRI 240/210)<br>800 h (AHRI 240/210)<br>2.8 |
| Heating days (DIN 4710:2003-01)<br>Heating degree days (total)<br>- DIN 4710:2003-01<br>- calculated using fractional bin hours (US method)<br>- which corresponds to HLH<br>CLH calculated using fractional bin hours (US method)<br>Ratio HLH/CLH | 242 + 91 = 333<br><br>3,478 K*day<br>3,875 K*day<br>(deviation +11 %)<br>7,318 h<br>710 h<br><br>9.3 … 10.3 | no data available |
| Mean difference to 20°C for heating season | 12.7 K<br>based on DIN 4710:2003-01 | 15.0 K<br>based on AHRI 240/210 |

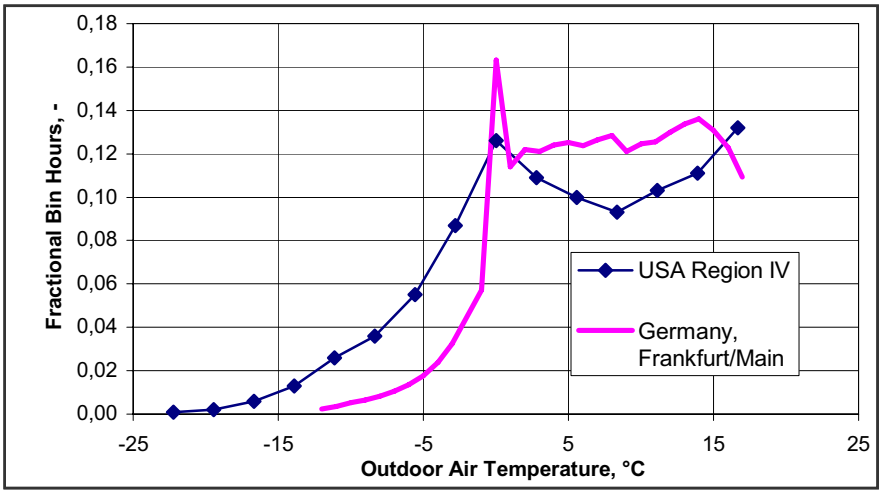



**Figure 2: Fractional bin hours**

With heating days being by far more than 300, the German winter is long. However, as a closer look at fractional bin hours showed, it is somewhat milder than that in New York (Figure 2, Table 2).

This might explain, at least to some extent, why US-American energy requirements for heat pumps are less strict than European ones.

## 4 CALCULATION OF HEATING SEASONAL PERFORMANCE FACTOR

### 4.1 VDI 4650 and AHRI 210/240 / Structure Comparison

How to get a HSPF out of a set of COP-values, taking into account all the other relevant data, is determined in German[9] VDI 4650 and in American AHRI Standard 210/240. The array of input data (Table 3) allows a structural comparison of both calculation methods.

**Table 3: Input data for VDI 4650 and AHRI 210/240**

| | **VDI 4650** | **AHRI 210/240** |
|---|---|---|
| Input data for ASPH (listed by manufacturer) | | |
| • performance at standard rating conditions | Qh(7), required at outdoor air temp. 7°C | Qh(47), required at 47°F = 8.3°C |
| • COP at application conditions | required for –7°C, 2°C, and 10°C | all available data can be implemented |
| • Qh at application conditions | N/A | |
| • cyclic degradation coefficient | not mentioned (apparently 0) | default value 0.25 |
| Heating plant data | | |
| • bivalence point | –10°C … +2°C | results from DHR*)/Qh(47) ratio |
| • ratio DHR*)/Qh(47) | N/A | min = 1, max = 2 (for Region IV) |
| • ratio of heat supplied by ASHP at outdoor air design temp. to building loads at this temp. | BL(d)/Qh(d) chosen from respective table | can be taken from SHPF calculations |
| • supplementary electric heating | not mentioned (most probably incl. in HSPF with COP = 1) | incl. in HSPF with COP = 1 |

[9] European prEN 153164.2 (preliminary standard); it is not endorsed yet.

| | | |
|---|---|---|
| • heating water supply temp. | 30°C … 55°C | N/A |
| • ratio Heating/DWP**) | default value 0.82/0.18 | N/A |
| Location and building data | | |
| • outdoor air design temp. | default value –10°C (for Frankfurt/Main) | default value 5°F = –15.0°C (for Region IV) |
| • heating limit outdoor air temp. | 10°C, 12°C or 15°C | default value 65°F = 18.3°C |
| • weather data distribution | cannot be changed | every particular data set can be implemented |
| • indoor design temp. | default value 20°C | default value 65°F = 18.3°C |

*) DHR = building design heating requirements (building loads multiplied by C = 0.77, a correction factor "which tends to improve the agreement between calculated and measured building loads")

**) DWP = domestic hot water production

The key differences between German and American HSPF calculation procedures are:
- Calculating acc. to VDI 4650 is a quick job once all the factors are chosen from the numerous tables; however, no further alterations are possible. Calculating acc. to AHRI 210/240 is more time consuming but it does not use any pre-calculated factors and allows for almost all likely alterations.
- AHRI 210/240 does and VDI 4650 does not allow for implementing alternating weather data distribution and cyclic performance degradation.
- VDI 4650 does and AHRI 210/240 does not account for domestic hot water production.
- Both standards deal quite differently with the bivalence point issue: AHRI 210/240 uses a ratio DHR/Qh(47), which indirectly determines the point, whereas in VDI 4650 this value can be chosen.

This leads to the following analysis approach:
- gleaning all relevant results for German ASHPs acc. to VDI 4650,
- using AHRI 210/240 to calculate HSPF values for German ASHPs for different weather conditions, an array of DHR values, and cyclic degradation factors ($C_d^h$).

### 4.2 Calculation Results acc. to VDI 4650

Calculations were conducted for the Stiebel-Eltron brand, which dominates the German ASHP market and shows higher COP values than other ASHPs examined under this paper.

Calculation results:
- The model WPL 18 fulfills the requirement of HSPF = 3.5
  - at bivalent-parallel operation with supplementary electric heating and no DWP (Figure 3):
    - for underfloor heating application (W35 = heating water supply temperature of 35°C) with the bivalence point being –2°C or lower,
    - for convector application (W45) with the bivalence point being –4°C or lower.
    - For radiator application (W55) this high efficiency will not be achieved.
  - at bivalent-alternative operation with supplement electric heater and no DWP:
    - for underfloor heating application (W35) with the bivalence point being –8°C or lower.
- In the calculation, the water supply temperature has to be fixed (e.g. W35, W45, or W55). Calculations with gliding supply temperature, important especially for the radiator application, are not possible.
- For bivalent-parallel operation with supplementary electric heating and no DWP, the ratio Qh(d)/BL(d) depends on the bivalence point (but, surprisingly, not on the application) and varies from 1.0 to 0.83 at –10°C (design temperature) and 2°C, respectively (Figure 3). The factor 0.83 appears unaccountably high, though (for comparison, see calculations acc. to AHRI 210/240).

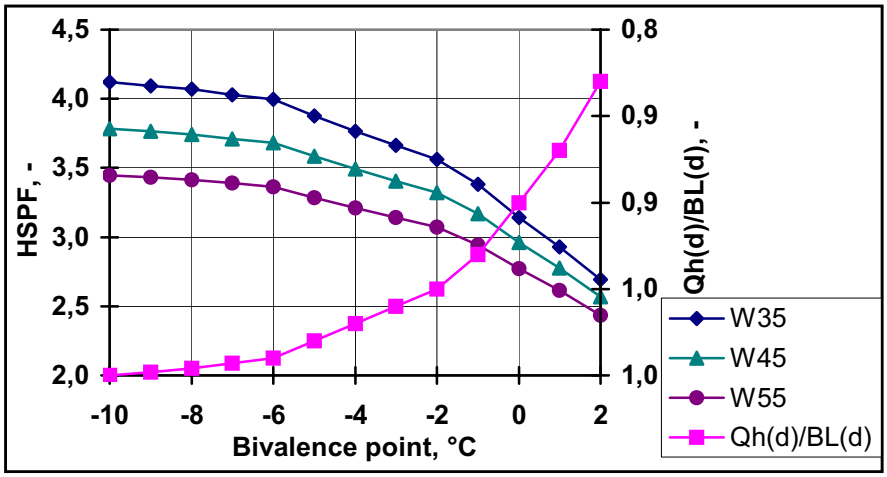



**Figure 3: Energy efficiency acc. to VDI 4650**

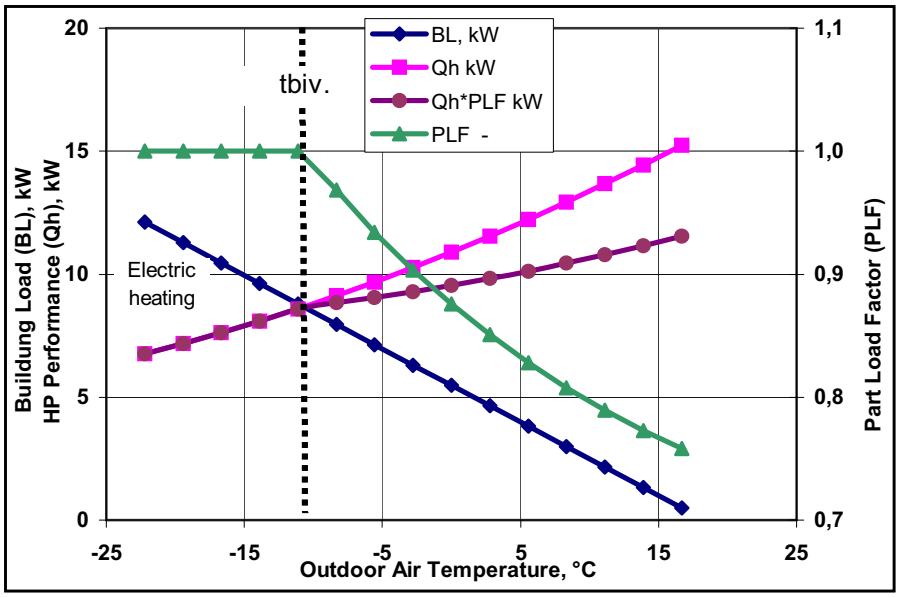



**Figure 4: Sample calculation acc. to AHRI 210/240:**
**DHL = $DHL_{min}$, $C_d^h$ = 0.25**

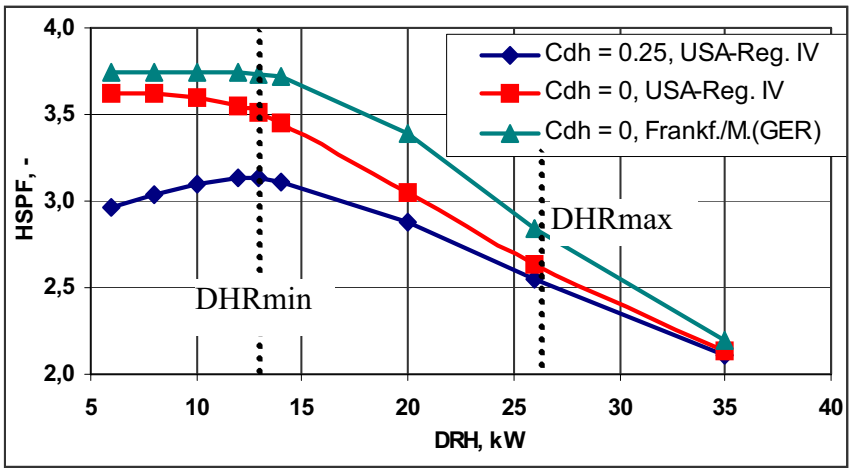



**Figure 5: Energy efficiency acc. to AHRI 210/240**

- For monovalent operation, the DHW ratio has almost no influence on the HSPF, which contradicts with the sound results given in Figure 3 as well as the field test results.
- For monovalent operation, a HSPF up to 4.1 can be achieved.

### 4.3 Calculations acc. to AHRI 210/240

The calculation method acc. to AHRI 210/240 can be very distinctly illustrated by the following sample calculation (Figure 4):

- building loads (BL) change linearly to outdoor air temperature,
- part load factor (PLF) remains 1.0 at temperatures below the bivalence point and declines accordingly afterwards,
- PLF reduces the heat pump performance at temperatures above the bivalence point (from Qh to Qh*PLF),
- at temperatures below the bivalence point, the difference between BL and Qh is covered by supplementary electric heating with COP = 1.

Calculations with various $C_d^h$ and weather data showed the following (Figure 5):

- the cyclic degradation factor ($C_d^h$) is of great importance, it causes a decrease in HSPF by up to 24 % (3.13 / 3.62 at $DRH_{min}$),
- using USA-Region IV weather data instead of German data leads to a decrease in HSPF by up to 10 % (3.05 / 3.39 at $DRH_{max}$).
- When the cyclic degradation factor is neglected and German weather data are used, a HSPF of 3.7 can even be achieved (at $DRH_{min}$).
- The ratio Qh(d)/BL(d) depends on the bivalence point and varies from 1.28 to 0.29 at –22.2°C and 2°C, respectively (1.0 corresponds to the design temperature of –15°C).

### 4.4 Comparison and Conclusions

The huge difference in energy requirements for European and American ASHPs (HSPF of 3.5 and 2.345, respectively) is merely of calculatory nature, i.e. it is mainly caused by the application of different calculation methods (esp. cyclic degradation factor) and different weather conditions. The same ASHP would achieve a HSPF of 4.1 when calculated acc. to VDI 4650 and of 3.7 when calculated acc. to AHRI 210/240 (factor 1.11).

Nevertheless, it does not explain away the fact that ASHPs in the US are of the air-to-air type and in Europe of the air-to-water type and that, for the same duty, the latter are bound to use more energy. Obviously, “soft reasons” like subsidies, environmental concerns, and strong advertising campaigns have led to European ASHPs being technically more elaborated than those in the US.

## 5 REFERENCES

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