INVESTIGATION OF THE BENEFITS OF THE VAPOUR INJECTION SCROLL COMPRESSOR IN HEAT PUMPS USING A SEASONAL EFFICIENCY MODEL

E. Winandy, Director Application Engineering, Emerson Climate Technologies, Welkenraedt, Belgium and Guy Hundy, Technical Consultant, Emerson Climate Technologies, Welkenraedt, Belgium

Abstract: A heat pump (HP) seasonal efficiency comparison method, recently reported, is used to generate data, which enables the effect of varying parameters to be investigated. The model can handle both space heating and domestic hot water requirements and takes account of evaporator and condenser size, compensated control, back-up direct heating, and defrost. In this paper the performance of similar sized air source heat pumps with various types of scroll including the vapour injected scroll is compared. Weather data can be used to establish space heating load patterns representative of various regions in Europe, and this information is combined with the HP performance to show how the HP copes with regional annual temperature cycles. Both air source and ground source can be modeled. Once the results obtained from the software has been verified by test data at a few key points, the seasonal performance can be investigated without the need for a long and costly test programme.

Key Words: ***heat pumps, seasonal performance, vapour injection, compressors***

1 INTRODUCTION

Testing resource is one of the major constraints in optimising components and operating conditions of heat pumps. This is particularly true with air source because climate control facilities are necessary. Heat pump performance can be derived from known compressor performance if the operating conditions of the compressor over the range of secondary flow temperatures can be adequately defined. Normally, for a compact brine/water or air/water heat pump the values of refrigerant superheat and subcooling are small and can be treated as constant over the operating range. The temperature differences at the condenser and evaporator need to be defined – these values will depend on relative heat exchanger size and may vary with operating conditions. They will normally be found from test data. This approach was reported by Winandy et al (2007), and one of the advantages of using software of this type is that the effects of changing various parameters can be readily explored prior to final test confirmation.

2 COMPARISON OF AIR/WATER HP WITH WPZ SINGLE POINT TEST DATA

In this example temperature differences (TD) representative of current practice have been chosen to take account of the fact that the air coil is usually operated with superheat at the outlet. The temperature difference on the outdoor coil will tend to reduce at lower air temperatures as it becomes more “oversized”. The heat exchanger TD characteristics shown in Figure 1 have been adopted. The refrigerant is R407C.

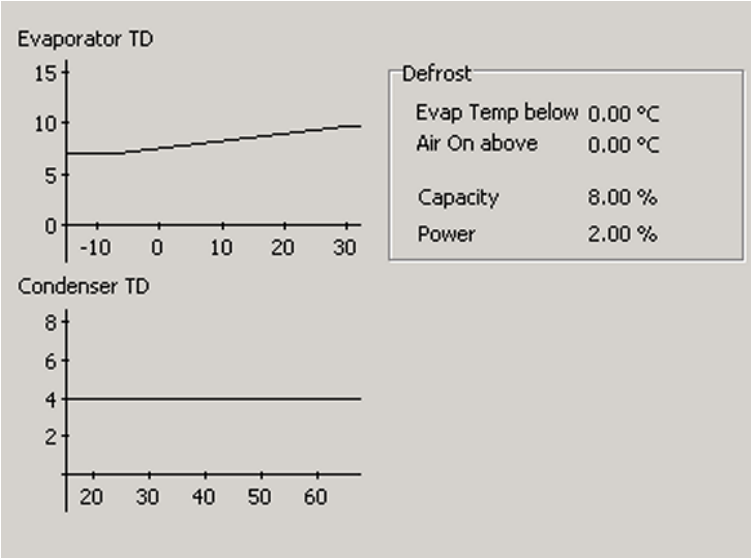

Figure 1: A/W Evaporator and temperature difference (Air Inlet - Dew Point Evaporation) and condenser temperature difference (Dew Point Condensation – Water Outlet)

The graphs show the heat exchanger TD over the outdoor temperature range –15 to 30°C. The evaporator TD has a minimum value of 7K at low air temperatures and increases to a maximum of 10K at 30°C air temperature. The condenser TD has been set at 4K and there is also a degradation factor for defrost. The defrost degradation reduces the average HP capacity by 8% and the power input by 2% when the air temperature is above zero degrees and when the evaporating temperature is below zero degrees. Both conditions must be met, and thus for air temperatures below zero, no degradation is applied – corresponding to dry, cold ambient conditions. The application and settings for defrost can be changed in the software. Compressor selection software is accessed to provide performance data at any allowable operating condition within the operating limits, and operating conditions and output is then adjusted according to the conditions shown in Table 1. This processed data forms the HP performance in terms of air and water temperatures.

Table 1: A/W HP parameter settings used in the model

Fan + pump power	Super-heat, K	sub-cool	Evaporator TD	Condenser TD	Defrost factor Capacity	Defrost factor Power	Defrost factor COP
0.28kW	4	0	7 – 10K	4K	-8%	-2%	-6%

.

The COPs of HPs derived from the model are shown in Figure 2. Two HPs, one containing the standard scroll ZH and the other containing a vapour injected scroll compressor, both using the settings shown in Table 1. The test points were chosen to correspond to the WPZ data at EN14511 conditions (2007). Test data taken from WPZ for two HPs is shown for comparison.

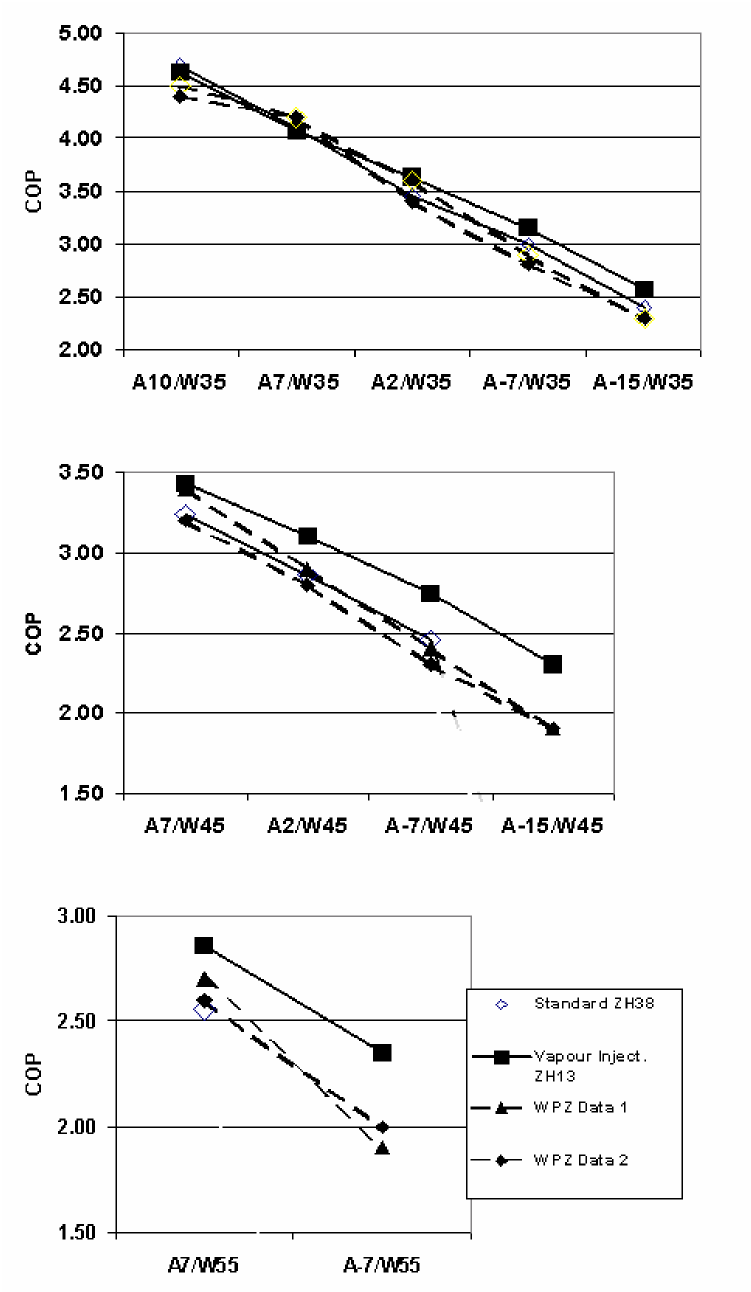

Figure 2: A/W COPs from model and from WPZ at water temperatures 35, 45 and 55°C

The model shows quite close correlation with the WPZ data for the standard scroll unit, and the COP advantage of the economised cycle with vapour injection is clearly shown. As expected the most gain is at high water temperatures where the operating pressure ratio is higher.

3 ADVANTAGES OF VAPOUR INJECTION

Vapour injection provides cooling for the compressor, extending the operation at low ambient temperatures into an area which is essential for many air source heat pumps, (Figure 3). This reduces the amount of back up heating and further improves seasonal efficiency. More capacity is also provided at lower outdoor air temperatures thus further reducing the need for back up heating at extreme conditions whilst at the same time allowing a compressor with 20% less displacement to do the same job.

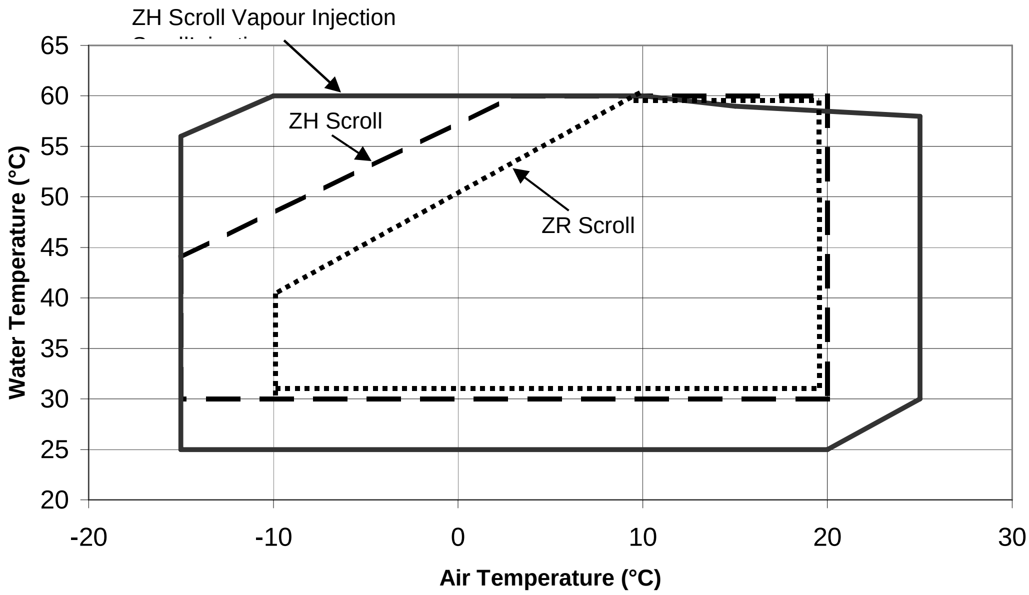

Figure 3: A/W Operating envelopes for heat pumps used in the model

4 SEASONAL HEATING PERFORMANCE WITH VAPOUR INJECTED SCROLL

Figure 4 shows the data for a vapour injected R407C scroll heat pump with the settings shown in Table 1. The water flow temperature is constant at 55°C, and the weather data is for Frankfurt. The weather data is in the format of 5K bins so that, for example, the 5°C bin contains the annual hours with air temperatures between 2.5 and 7.5°C. The number of bins is a matter of judgement and it cannot be assumed that smaller temperature bands will give a more accurate result because the actual weather will always be different to any prediction. Provided the weather data is reasonably representative of the location, a good comparison can be made. The heat pump is sized for 20% excess capacity at +2°C air temp. Below 0°C, capacity becomes inadequate and back up heating required. This is shown as Direct Heating in Figure 4 and dark shaded in Figure 5. The area of the histogram in Figure 5 represents the kW heating, and illustrates the relatively small amount of back up heating required.

-

Ambient, °C	- 15.0	- 10.0	- 5.0	0.0	5.0	10.0	15.0	Total
Hours	4	60	208	1003	1960	1906	1802	**6943**
Evaporating Temp, °C	- 22.00	- 17.00	- 12.14	- 7.50	- 2.86	1.79	6.43	
Heating								
Condensing Temp, °C	59.00	59.00	59.00	59.00	59.00	59.00	59.00	
Load, kW	17.25	14.78	12.32	9.86	7.39	4.93	2.46	
Capacity, kW	8.42	9.41	10.55	10.85	12.13	14.73	16.43	
Input Power inc Fan, kW	4.17	4.24	4.32	4.32	4.40	4.57	4.66	
Run hours	4.00	60.00	208.00	911.35	1194.23	637.46	270.21	
% Run Time	100.00	100.00	100.00	90.86	60.93	33.45	15.00	
Capacity x Run Time, kWh	33.67	564.58	2193.55	9885.12	14487.67	9392.34	4439.93	**40996.9**
Input, kWh	16.68	254.54	898.30	3932.52	5251.08	2912.89	1259.81	**14525.8**
Direct Heating, kWh	35.32	322.42	368.89	0.00	0.00	0.00	0.00	**726.6**
Total Heating Input, kWh	52.00	576.96	1267.20	3932.52	5251.08	2912.89	1259.81	**15252.5**

SCOP = 2.69

Figure 4 SCOP calculation – Location: Frankfurt, constant water temperature 55°C

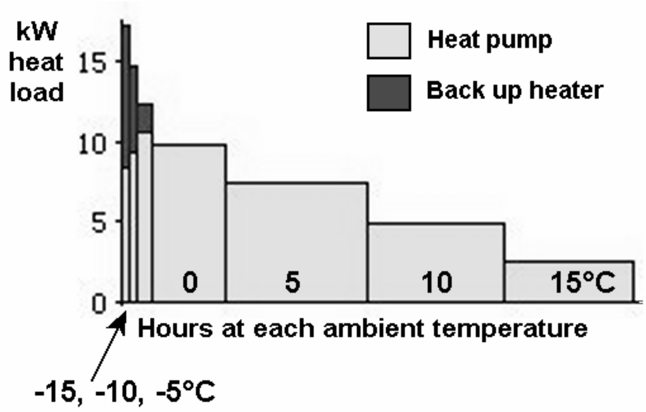

Figure 5: Heat load in each ambient bin. Area represents kWh

The model can be configured for compensated control as illustrated in Figures 6 and 7. The conditions are the same as above – the only change made is to apply compensated control instead of a constant water temperature of 55°C. The water temperature is set at 55°C for ambient –10°C and is reduced by 0.7K for each degree rise in ambient temperature, to compensate for lower building heat loss. The improved SCOP results from lower condensing temperatures during most of the season and correspondingly lower compressor run hours.

Ambient, °C	- 15.0	- 10.0	- 5.0	0.0	5.0	10.0	15.0	Total
Hours	4	60	208	1003	1960	1906	1802	**6943**
Evaporating Temp, °C	- 22.00	- 17.00	- 12.14	- 7.50	- 2.86	1.79	6.43	
Heating								
Condensing Temp, °C	62.50	59.00	55.50	52.00	48.50	45.00	41.50	
Load, kW	17.25	14.78	12.32	9.86	7.39	4.93	2.46	
Capacity, kW	0.00	9.41	10.43	10.72	12.06	14.79	16.67	
Input Power inc Fan, kW	0.00	4.24	4.03	3.78	3.63	3.55	3.40	
Run hours	0.00	60.00	208.00	921.71	1200.98	635.17	266.33	
% Run Time	0.00	100.00	100.00	91.90	61.27	33.32	14.78	
Capacity x Run Time, kWh	0.00	564.58	2170.37	9885.12	14487.67	9392.34	4439.93	**40940.0**
Input, kWh	0.00	254.54	837.98	3483.07	4356.63	2255.64	906.08	**12093.9**
Direct Heating, kWh	68.99	322.42	392.08	0.00	0.00	0.00	0.00	**783.5**
Total Heating Input, kWh	68.99	576.96	1230.06	3483.07	4356.63	2255.64	906.08	**12877.4**

SCOP = 3.18

Figure 6: SCOP calculation – Location: Frankfurt, compensated control - water temperature decreased by 0.7K per degree rise in ambient temperature above –10°C

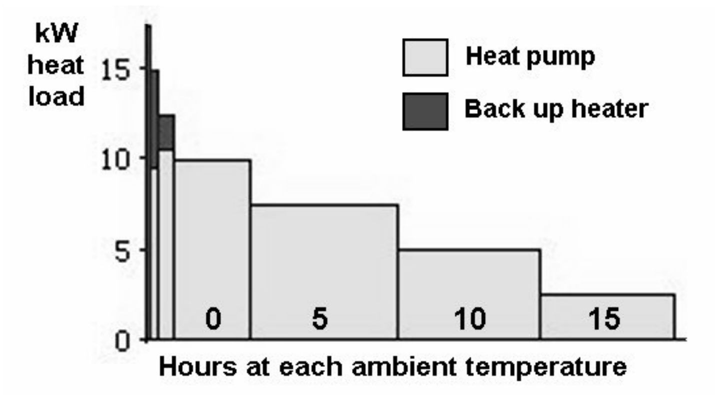

Figure 7: Heat load in each ambient bin. All heat in lowest bin supplied by back up heater

Compensated control has been set to give a maximum water temperature of 55°C at –10°C air temperature. If the air temperature falls below this value the water temperature is correspondingly increased, and there are just 4 hours in the –15°C bin. This demands a condensing temperature of 62.5°C (Figure 6) which is outside the operating envelope (Figure 3). The calculation has been made with this heat supplied 100% by the back up heater. Other options are possible but the overall result changes very little due to the small number of hours involved.

The envelope of the standard ZH scroll restricts its use at low ambient temperatures in this application. At air temperatures below –5°C water temperature of 55°C cannot be delivered, as can be seen from Figure 3. In this situation the SCOP is again calculated using 100% back up heat for these low ambient bins. A summary of the SCOP comparison is given in Table 2.

Table 2: SCOP comparison for heating only, location – Frankfurt

Heat pump compressor	SCOP Constant water temperature 55°C	SCOP Compensated Control with water temperature 55°C at –10°C ambient
Scroll ZH	2.06	2.85
Scroll ZHKVE, Vapour Injected	2.69	3.18

6 ADDITION OF DOMESTIC HOT WATER (DHW)

DHW can be added in the model as a percentage of the heating load. In this example the total heating load at 2°C is the same as before, except that 20% is taken for DHW at 58°C. The HP is assumed to cycle between the DHW load and the heating load as required, with the condensing temperature adjusted according to the compensated control requirement. This is set up in the same way as before.

The calculation for SCOP now includes the bins for summer period where the load is DHW only. This is shown in Figure 8. When the air temperature is 25°C and above the operating conditions are outside the envelope and the calculation is made on the assumption of back up heating for DHW at these conditions. Alternative options are pressure reducing valve to enable the compressor operation to continue or solar heat, and both of these options would benefit the SCOP. When the air temperature is –5°C and below back up heating is required for DHW (The compressor hours are prioritised for heating). Back up heating in these bins could be reduced with a larger compressor. At –15°C the compressor does not run.

Ambient, °C	-15.0	-10.0	-5.0	0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	Total
Hours	4	60	208	1003	1960	1906	1802	1250	492	72	3	**6943**
Evaporating Temp, °C	-22.00	-17.00	-12.14	-7.50	-2.86	1.79	6.43	11.07	15.71	20.36	25.00	
Heating												
Condensing Temp, °C	62.50	59.00	55.50	52.00	48.50	45.00	41.50	39.00	39.00	39.00	39.00	
Load, kW	13.81	11.83	9.86	7.89	5.92	3.94	1.97	0.00	0.00	0.00	0.00	
Capacity, kW	0.00	9.41	10.43	10.72	12.06	14.79	16.67	0.00	0.00	0.00	0.00	
Input Power inc Fan, kW	0.00	4.24	4.03	3.78	3.63	3.55	3.40	0.00	0.00	0.00	0.00	
Run hours	0.00	60.00	196.57	737.79	961.32	508.42	213.19	0.00	0.00	0.00	0.00	
% Run Time	0.00	100.00	94.51	73.56	49.05	26.67	11.83	0.00	0.00	0.00	0.00	
Capacity x Run Time, kWh	0.00	564.58	2051.11	7912.56	11596.67	7518.11	3553.94	0.00	0.00	0.00	0.00	**33197.0**
Input, kWh	0.00	254.54	791.94	2788.02	3487.27	1805.53	725.27	0.00	0.00	0.00	0.00	**9852.6**
Direct Heating, kWh	55.22	145.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**200.6**
Total Heating Input, kWh	55.22	399.96	791.94	2788.02	3487.27	1805.53	725.27	0.00	0.00	0.00	0.00	**10053.2**
DHW												
Condensing Temp, °C	62.00	62.00	62.00	62.00	62.00	62.00	62.00	62.00	62.00	62.00	62.00	
Load, kW	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	
Capacity, kW	0.00	0.00	10.65	10.91	12.16	14.73	16.39	18.20	0.00	0.00	0.00	
Input Power inc Fan, kW	0.00	0.00	4.60	4.59	4.67	4.85	4.94	5.04	0.00	0.00	0.00	
Run Hours	0.00	0.00	11.43	163.13	285.98	229.60	195.06	121.85	0.00	0.00	0.00	
% Run Time	0.00	0.00	5.49	16.26	14.59	12.05	10.82	9.75	0.00	0.00	0.00	
Capacity x Run Time, kWh	0.00	0.00	121.72	1779.32	3477.04	3381.24	3196.75	2217.50	0.00	0.00	0.00	
Input, kWh	0.00	0.00	52.55	748.26	1335.00	1112.68	963.62	613.97	0.00	0.00	0.00	**4826.1**
Direct heating, kWh	7.10	106.44	1.19	0.00	0.00	0.00	0.00	0.00	872.81	127.73	5.32	**1120.6**
Total DHW Input, kWh	7.10	106.44	53.74	748.26	1335.00	1112.68	963.62	613.97	872.81	127.73	5.32	
Total % Run Time	**0.00**	**100.00**	**100.00**	**89.82**	**63.64**	**38.72**	**22.66**	**9.75**	**0.00**	**0.00**	**0.00**	

SCOP = 3.05

Figure 8: SCOP calculation – Location: Frankfurt, compensated control, with DHW at 58°C, vapour injected scroll

A comparison between three scrolls has been made for these conditions and loads, each HP having approximately the same capacity at 2/55°. The ZR scroll is the standard air conditioning compressor, the ZH is the standard heating compressor and these are compared wit the vapour injected equivalent. These results are summarised in Figure 9.

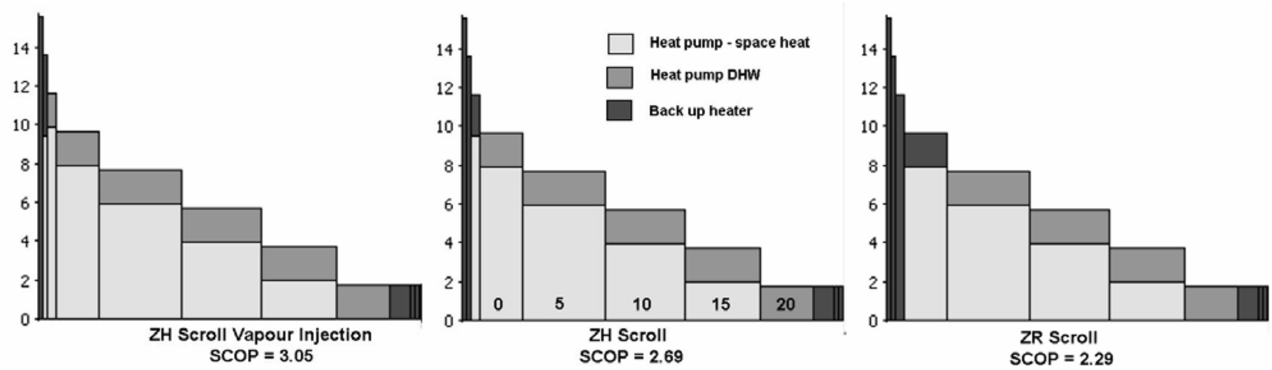

Figure 9: SCOP results comparing standard scroll types and vapour injection type

7 BRINE/WATER HEAT PUMPS

Brine/Water heat pumps are modelled in a similar way to the air source type, except that the brine inlet temperature is treated as constant. Whilst brine temperature may change, the seasonal change is relatively small and is not weather dependent. Vapour injected scroll offers less advantage over conventional types because the envelope requirement is less and because the evaporating temperature remains relatively high even in low ambient conditions.

8 CONCLUSIONS

The operating envelope allows the vapour injected compressor to operate in a region suitable for boiler replacement heat systems using radiators which require 55°C + temps at low ambient, and this helps to enhance seasonal COP

The model is found to closely track test COP data at specific operating points when the air source HP is tested at EN14511 conditions

The model can be used to explore the effects of various locations, various sizes of heat pump (relative to load), fixed water flow temperature and compensated control, defrost de-rating effects, and varied coil and Heat exchanger TDs.

The examples provided demonstrate the performance advantage of vapour injection for air source heat pumps, when compared to conventional scroll technology.

9 REFERENCES

Winandy E, Hundy G, Hewitt N, “Modelling Air Source Heat Pump Seasonal Efficiency”, International Congress of Refrigeration 2007, Beijing

WPZ Bulletin 02-2007, Wäemepumpen-Testzentrum WPZ, CH-9470 Buchs

Meteonorm Global Meteorological Database for Solar Energy and Applied Meteorology, www.meteotest.ch/en