IEA HPP ANNEX 36: QUALITY INSTALLATION / QUALITY MAINTENANCE SENSITIVITY ANALYSIS

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Abstract: The paper summarizes the goals and planned activities to be undertaken by the participants in Annex 36. Some background information and status of Annex work specific to each participant is provided as well.

Key Words: heat pumps, installation, maintenance, performance, quality assurance

1 INTRODUCTION

Heat pump operating performance (capacity, efficiency, etc.) is related to how well the equipment is actually installed and subsequently maintained in the field. Yet, a difficulty in promoting sound installation and maintenance practices is that the marketplace often incentivizes 'cutting corners' so as to keep first-cost pricing low, resulting in poorly performing equipment and poor value received by the customer. Generally, an underlying cause of this predicament is that the various industry participants (e.g., original equipment manufacturers, distributors, designers, installers, etc.) – as well as the ultimate building owners/operators/customers – do not appreciate how small deviations in installation and maintenance quality impact equipment performance.

It is widely recognized that residential and commercial heat pump equipment suffers significant performance loss (i.e., capacity and efficiency) depending on how the components are sized, matched, installed, and subsequently field-maintained. Annex 36 is evaluating how installation and/or maintenance deficiencies cause heat pumps to perform inefficiently and waste energy. Specifically to be investigated is the extent that operational deviations are significant, whether the deviations (when combined) have an additive effect on heat pump performance, and whether some deviations (among various country-specific equipment types and locations) have larger impacts than others.

In November 2010, the Executive Committee of the International Energy Agency (IEA) Heat Pump Program (HPP) officially approved the Annex. The confirmed Participants of Annex 36 (at time of writing) are France, Sweden, the United Kingdom, and the United States (Operating Agent).

2 PLANNED WORK SCOPE AND TIMETABLE

In conjunction with the ASHRAE Summer Meeting (Albuquerque, NM, USA; June 2010), an initial meeting was held among the confirmed Participants and several other potentially interested countries (Canada, Germany, Korea, and Switzerland). The participants deliberated on the work and established the following timeframe for the work to be undertaken:

Start Date	End Date	Activity
Nov 2010	Apr 2011	Task 1: Critical literature survey
May 2011	Oct 2011	Task 2: Identify sensitivity parameters
Nov 2011	Jul 2012	Task 3: Modelling and/or lab-controlled measurements
Aug 2012	Apr 2013	Task 4: Simulations on seasonal impacts
May 2013	Nov 2013	Task 5: Report and information dissemination

Anticipated upcoming meetings of the Participants are:

May 2011: 1st meeting (in conjunction with 10th IEA Heat Pump Conference in Tokyo, Japan)

Jun 2012: 2nd meeting (in conjunction with ASHRAE or Purdue Conferences) in the U.S.

Mid-2013: 3rd meeting at a venue still to be confirmed.

Additionally, web conferences will be scheduled on an as-needed basis.

Work scope:

Task 1 Critical literature survey: Literature review and critical analysis of the results from prior related research to identify quality installation (QI) & quality maintenance (QM) metrics and to secure quantitative and qualitative impacts of various deviations from the specified levels recommended in industry's relevant QI & QM standards.

Task 2 Identify sensitivity parameters: Identify Participant-specific QI & QM elements to be included in the Participant's sensitivity investigation.

Task 3 Modelling, laboratory-controlled measurements, and/or in-situ investigations: Undertaken to verify the results provided by earlier researchers, to fill-in 'holes' in regard to quantifying the impacts of QI & QM vs. non-QI & QM applications, and to better understand the singular and additive impacts on equipment effectiveness.

Task 4 Simulations on seasonality impacts: Determine the role that seasonal temperature differences have on the varied QI & QM elements and the resultant impact on heat pump performance.

Task 5 Report and information dissemination: Address the results of the tasks above.

3 PARTICIPANTS' WORK STATUS AND PLANS

3.1 France

French team lead – Jean-Marc Lebreton, Électricité de France

Task 1: Literature Survey. A statistical heat pump owner satisfaction survey (based on phone interviews) was completed during June and July 2009. The survey was concerned with heat pumps installed from January 2005 to October 2008. Its aims were to 1) ascertain the customers' level of satisfaction and 2) to understand the main problems they experienced with their heat pumps.

Generally, customers' overall satisfaction level was found to be high except for maintenance after sale. About 25 % of the owners responding to the survey noted some technical problems with their heat pump. The origins of the problems were classified as a function of their relative weight in the customers' answers. Based on feedback from some insurers' experts and legal experts, the major problem areas concerned heat pump performance, payback (cost of operation), and comfort.

Task 2: Sensitivity parameters identified from Task 1 will be completed by a panel of experts.

Task 3: Field and laboratory performance tests have been, and continue to be, conducted on several heat pumps, both for space heating and water heating applications. These tests are intended to evaluate, for example, the maximum deviation in coefficient of performance

(COP) between field test and lab test for a heat pump system installed according to the accepted rules of the art (or rules of thumb).

Task 4: The impact of some Quality Installation problems could be evaluated in the lab in relationship with different climate conditions.

Task 5: A country report will be prepared to summarize the work conducted in Tasks 1-4. Information on the evaluation of different performance measurement methods under field test conditions and recommendation for some that are more cost-effective could be included in the final report.

3.2 Sweden

Sweden team leads – Lennart Rolfsman, SP Technical Research Institute of Sweden; Björn Palm, Royal Institute of Technology (KTH); Jan-Erik Nowacki, Swedish Heat Pump Association (SVEP)

Between 1982 and 1992 about 33 000 geothermal installations were made in Sweden. From 1993 until now about 360 000 more installations have been made. It is not clear how many units have been decommissioned, but a fair guess is that at least 350 000 units are currently active. In Sweden today, between 850 000 and 1 000 000 heat pumps are in use for all kinds of applications. They can be estimated to recover 17-18 TWh of solar energy yearly. About half of that is solar-geothermal heat stored in the ground by the sun. Geothermal heat pumps constitute about 38 % of the total number of heat pumps.

3.2.1 KTH and SVEP

Heat pump failure statistics. An important part of the KTH and SVEP contribution to Annex 36 will be based on analysis of failure statistics. In the present paper, some initial information will be given. The main source of information is the insurance company Folksam, one of the largest insurance companies in Sweden, covering about 25 % of the Swedish market for home insurance. Folksam has, for many years, collected disturbance reports on Swedish heat pumps and put the basic failure (disturbance) statistics on the Internet (Folksam 2009). Together with this public data, a lot of other internal data was also collected simultaneously (e.g., resulting cost for each type of failure). We also have access to a large number of service reports from a few installers.

The disturbances were sorted into the following categories:

- Compressor
- Switch valve between radiators/hot tap water
- Brine pump
- Electronic control cards
- Brine leakage
- Refrigerant leakage
- Hot water boiler
- Other disturbances

Cumulatively, 22 000 disturbances were recorded by all insurance companies since 1999. The age of the failing unit was also recorded and categorized into three groups depending on when the failure occurred: 0-5 years from installation and 6-10 years after installation and older units. Around 30 different manufacturers were represented, and the number of involved installers was in the order of 500. Unfortunately, the number of sold units of each make is not available to us and thus it has not been possible to tell which makes are the most error prone or “the best”. The types and frequencies of various disturbances can be seen in Figure 1 below.

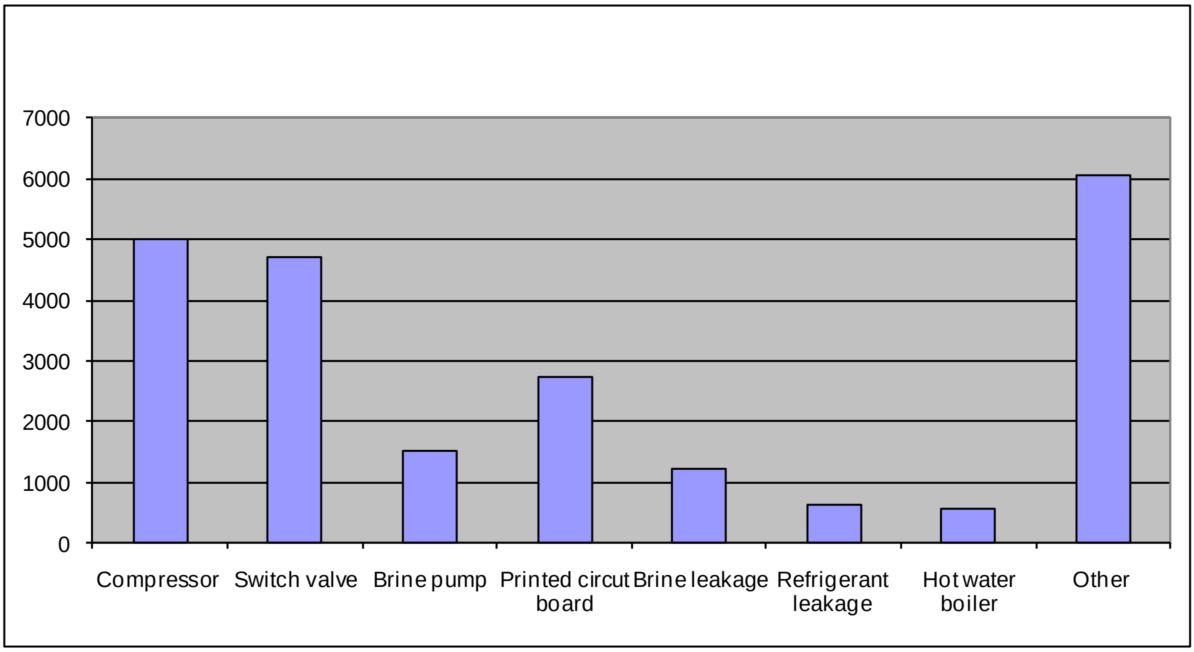

Figure 1: Number of disturbances (failures) for each major type of failure during 10 years for bedrock and horizontal ground sea/lake heat pumps – all insurance companies

About 15 500 of the disturbances took place during the first five years. A more detailed analysis of the failures will be presented later in the project.

According to Jan Snaar at Folksam, the home insurance companies in Sweden have paid 630 MSEK (about 100 million US$) for heat pumps during the ten-year period from 1999 to 2009. A total of 62 000 failures were reported during these years. During the same time period, the total running time for all heat pumps in Sweden is estimated by us to be about 4.7 million years [SVEP 2010]. That means an average cost to the insurance companies of about 135 SEK/year/heat pump (about 20 US$/heat pump/year). An average cost of 10 000 SEK/failure (1 500 US$/failure) seems rather high though. This was for all kinds of heat pumps - geothermal and others. Of course the total costs are higher, as not all disturbances are reported to or paid by the insurance companies.

In contrast, the value of the heat taken from nature to the heat pump owners today is estimated at 20 GSEK/year (3 billion US$) assuming an energy price of 1.3 SEK/kWh (0.2 US$/kWh). If 850 000 heat pumps were running, costing 135 SEK/year for disturbances, that amounts to a total cost for failures of 115 MSEK (18 million US$/year) or 0.6 % of the value of recovered energy from nature. Totally the service and maintenance cost of the heat pumps are in the magnitude of 1 %.

Best Practice in installation and use. A second part of the KTH/SVEP work planned is to collect Best Practices for installation and use of heat pumps (from a Swedish perspective). The intention is to present this information in a format suitable for reading by installers as well as by the private owner of a heat pump.

3.2.2 SP Technical Research Institute

There are many types of heat pumps installed in Sweden as mentioned above. The market of industrial heat pump applications, especially in the food industry, is less well understood. Almost all 40 bar piston (reciprocating) compressors from the major suppliers delivered before 2006 were sent to Swedish food industries. The rest are installed in Norway. The subsidies for these compressors were a major incentive for these heat pump installations during the early 80´s. Electricity during the 70´s and 80´s was regarded as cheap and there was no alternative natural gas system available. All the early machines used R12 and were changed during the late 90´s with ammonia or R134a. The market for very large (>10 MW) heat pumps connected to district heating systems is better understood owing to several technical publications on the subject. Today those machines are still operating on R22, but are not allowed to recharge. Therefore they are carefully monitored with very qualified instrumentation.

SP's technical project contribution to Annex 36 (now financed and ready to start) will focus on larger heat pumps intended for multifamily and commercial building space heating and domestic (tap) water heating applications. This market is estimated from a number of sources today to be in the range of 200-400 million Euro (270-540 million US$) annually for new installations. The first such installations were made in the late 60´s. Today many or most multi family buildings are in areas served by district heating systems. There is a tendency now to move many of these buildings as well as buildings in areas without the district heating option toward heat pump systems. The main heat pump types are:

- Heat pumps using exhaust ventilation air as a source for heating of tap water
- Geothermal heat pumps with vertical bore holes/heat exchangers using radiator systems for space heat distribution
- Very few air to water heat pumps.

The installed units are from different sources:

- Small machines from the large producers using many in parallel
- Dedicated custom designs built by installers, mainly coming from the commercial sector but also from industrial refrigeration suppliers
- Chillers from large multinational producers like Carrier, Trane, Daikin, etc.
- Chillers from smaller French or Italian producers.

The main issue is that these larger installations do not perform as well as the smaller heat pumps aimed at single family homes. These smaller heat pumps have, after 25-30 years, become a mature, generally well understood technology. This does not mean that there is not much still to be done regarding field installations of smaller units, systems and their maintenance.

3.3 United Kingdom

UK team leads – Penny Dunbabin and Chris Wickins, Department of Energy and Climate Change (DECC)

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The UK Energy Saving Trust (EST) is currently undertaking a field trial of domestic heat pumps. In the first year, 83 systems were monitored, covering a range of technologies (ground to water, water to water, air to water and exhaust air) and a range of heat emitters (under floor heating, radiators; each with and without domestic hot water production). Note that there is negligible use of air conditioning in UK homes. The results from the first year showed a wide range of "as-installed" performance, from good to poor. This study, by DECC and EST's contractors, Gastec and EA Technology, investigates the reasons for underperformance, which fall into five categories:

- Heat pump incorrectly sized for the property
- Ground loop incorrectly sized, or problems with borehole, or loss of glycol
- Heat emitters incorrectly specified
- Domestic hot water cylinders incorrectly sized
- Excessive use of supplementary heating, hot water immersion or circulation pumps.

Two examples of heat pumps burdened with poor installation issues during the first year (incorrectly sized ground loop, and incorrectly sized heat pump system) are highlighted below. First is a ground source heat pump site that supplies heat to underfloor heating, radiators and domestic hot water. The hot water is also heated by a solar thermal panel. Figure 2 shows the ground flow supply and return temperatures for a period of 3 days during a cold spell in January 2010.

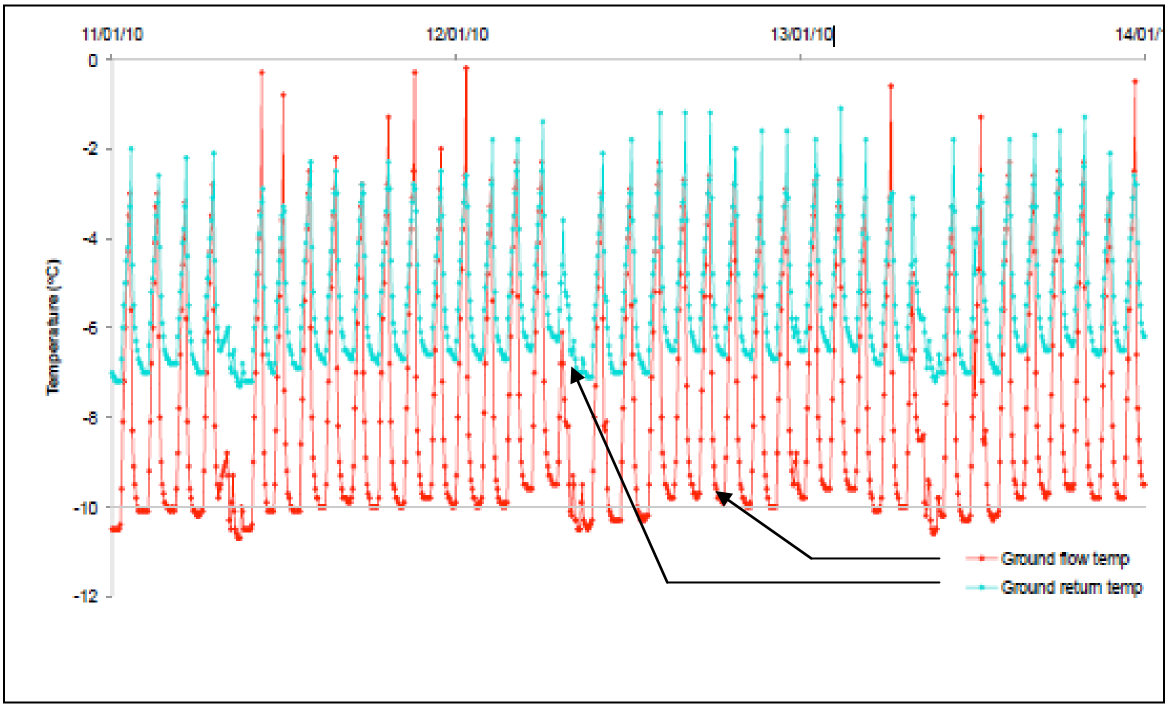

Figure 2: Ground flow & return temperatures of a ground source heat pump in January.

It can be seen that both flow and return temperatures are considerably lower than they should be, dropping to -10 °C and -7 °C respectively. This inevitably has an effect on the performance. Figure 3 shows the heat output from and electrical power supplied to the heat pump as a function of ground flow temperature entering the heat pump. At a ground flow temperature of 2 °C and central heating (CH) loop flow temperature of 35 °C, the COP of the heat pump is 3.17. At -7 °C, the COP is around 2.2. (Note: the COP here is for the full system including the heat pump electric power input and input to all auxiliary devices including circulation pumps.) The heat pump required frequent manual resets. The ground loop is clearly undersized, which leads to the borehole freezing. Similar results were found on a number of sites, including those with horizontal ground loops.

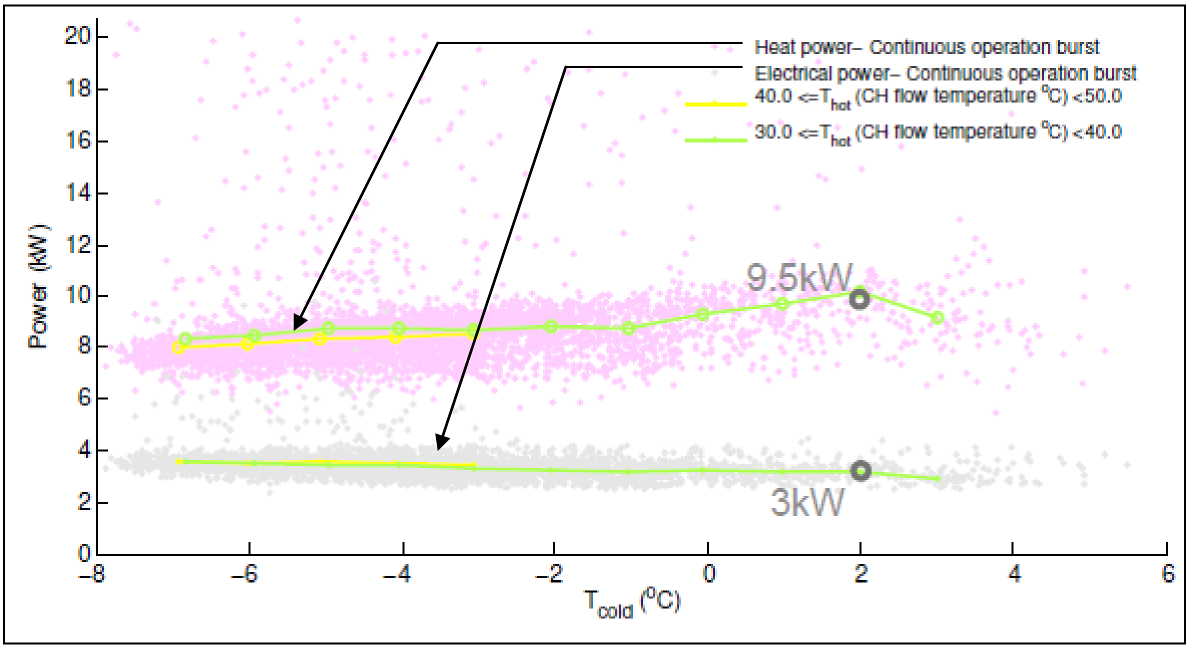

Figure 3: Electrical input and heat output as a function of ground flow temperature.

The second example is one of a heat pump undersized for the application (Figure 4). In order to size heat pumps correctly for the load, detailed heat calculations must be carried out. In the example below, a ground source heat pump was used to heat an underfloor system and radiators. The heat pump was rated at 8 kW, but had two supplementary direct electric heaters, each rated at 2.5 kW. Figure 4 shows a scatter plot of 20 minute readings of electricity input and heat output. Underneath and to the left are histograms of the points.

It can be seen that the heat pump itself is operating as expected (cluster of points to the left, at about 8 kW heat output – 20-minute average COP ranges between 3 and 4). However, there are two other clusters, at around 10 kW and 13 kW heat output for which the average system COP is 2 or less. These are due to operation of the backup electrical heaters. Note from the histogram that the heat pump spends most of its time operating in these ranges. This is an extreme example of under-sizing. There is no evidence of systematic under-sizing in this field trial, but several other heat pumps have been undersized.

The small chart with the vertical bars in the lower left quadrant of Figure 4 is a magnified version of the left hand side of upper (number of occurrences) histogram under the scatter chart. It shows that there are many points with an electrical burst power of around 10 W. This is due to the operation of a circulation pump. There are two smaller bars at 70 W and 150 W respectively. These refer to other circulation pumps, but it is clear that they run intermittently, thereby minimizing parasitic loads. On some other sites, circulation pumps in the heating system and even in the ground loop system are over-used. This has the effect of reducing system efficiency.

The UK proposal for their contribution to Annex 36 is outlined below.

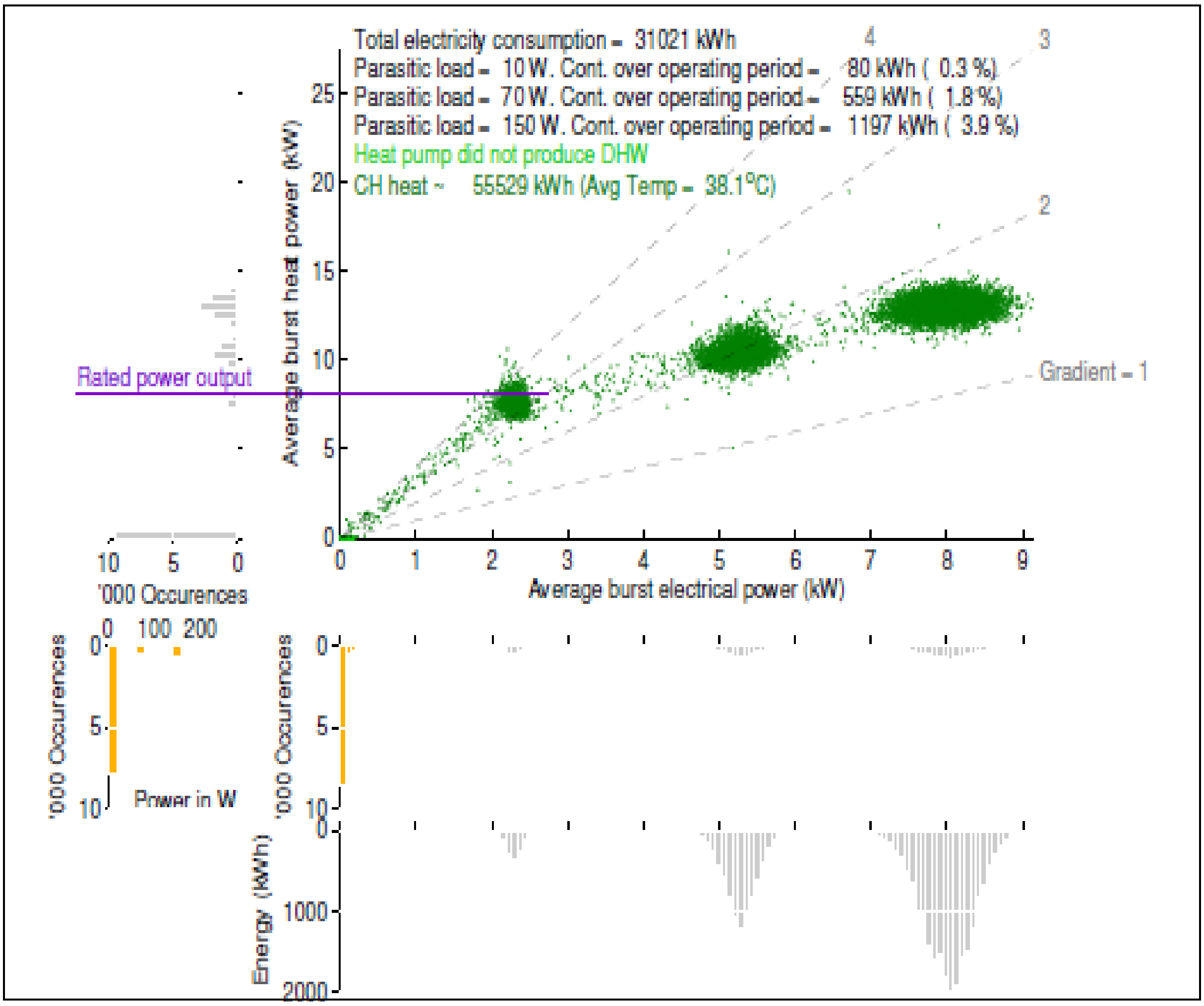

Figure 4: Scatter plot of electrical input to and heat output from a ground source heat pump with two integral backup electrical heaters.

Task 2: Identify Sensitivity Parameters.

The UK will provide a list of the parameters to be investigated in the field trials. These include:

- Sizing of the heat pumps relative to the heat loss of the house
- Sizing of the radiators/under floor system and temperature at which space heating is delivered
- Sizing of ground loop (if appropriate)
- Possible glycol leaks (if applicable)
- Possible freezing of borehole (if applicable)
- Use of pumps & defrost schedules
- Frequency of cycling of the heat pump (some pumps cycle very frequently, which could shorten the lifetime of the compressor)
- Auxiliary heating
- Control schedules
- Hot water tank size and losses
- Efficiency of hot water heating as opposed to space heating
- Insulation levels of pipes (for pumps located in sheds, rather than in the house).

Task 3: In Situ Field Trials.

Manufacturers will inspect each site in the trial. Based on the analysis and inspections, they will undertake a range of modifications to heat pumps which have poor performance. These include:

- Re-drilling a borehole on one ground source heat pump with a frozen borehole
- Topping up glycol levels if appropriate (only on a small number of sites)
- Reducing the frequency of defrost schedules and use of auxiliary pumps in order to improve system efficiency, if appropriate
- Installing buffer tanks if appropriate, where the heat pump cycles too frequently
- Changing control schedules to reduce cycling, if appropriate
- Changing periods of operation
- Increasing the size of the radiators and operating at lower temperature, if appropriate
- In a few cases, where the heat pump has clearly been incorrectly sized for the house, a new heat pump will be installed.

The trials will continue for another year. By comparing the results from the first and second years of the trial, it should be possible to establish whether the undertaken modifications resulted in better performance or not. The project will examine heat pump sizing strategies carefully. Sizing strategies vary from country to country; for example, in Sweden, where electricity is relatively cheap and has a low carbon factor, heat pumps may be sized to provide base load heat, while in Germany (where electricity is carbon intensive) they must be sized to meet 90 % of maximum demand. The heat loss coefficient will be calculated for each house in the trial and contractors will comment on whether each heat pump has been sized appropriately. The final report will produce recommendations on sizing as a function of house type (e.g., date of construction, solid walled or cavity walled, house size, etc). The seasonal performance factor will be presented for each heat pump and compared to the manufacturers' value. The final report from the trials is expected in December 2011, so the results will be available in time for the completion of Task 3 of Annex 36 (November 2011-July 2012).

Task 4: Simulations on Seasonal Efficiency.

The report from the trials will include the following analysis:

- Identification of sites for which heat pumps appear to be inappropriately sized and analysis of their seasonal performance factors (SPFs).
- Examination of the operational strategies (defrost, circulation pump use, temperature curves, time of usage) in order to establish which modifications have resulted in improvements in performance in the second year.
- Examination of the effect on SPF of the size of radiators and the temperature at which heat is supplied. Investigation of changes in SPF when modifications are made.
- Examination of sites where glycol loss appears to be a problem, and measurement of the annual SPF before and after rectification.
- Analysis of SPF for domestic water heating and recommendations on how to improve water heating efficiency (where possible).

3.4 United States

US team leads – Glenn Hourahan, ACCA; Piotr Domanski, NIST

The US project will develop an understanding of the impact of different commissioning parameters on the performance of heat pumps installed in a single-family house. The analysis will combine building effects, equipment effects, and climate effects in a comprehensive evaluation of the impact of installation faults on the annual energy consumption.

The two main elements of the project will be a controlled laboratory investigation of quality installation issues impacting heat pumps and building/heat pump seasonal simulations for different building/heat pump fault scenarios, different climates, and housing structures. The scope of commissioning parameters to be evaluated includes:

1. Building subsystem
   a. Duct leakage (unconditioned space): 0 % to 50 % of the supply air flow rate
   b. Supply air flow misbalance (room-to-room): - 30 % to 30 %
2. Residential split, air-to-air heat pump with seasonal energy efficiency ratio (SEER) 14
   a. Equipment sizing: 90 % to 200 % of load calculations; 10 % to 25 % intervals
   b. Indoor coil airflow: 50 % to 120 % of design airflow; 10 % to 25 % intervals
   c. Refrigerant charge
      - TXV: -10 °C to 10 °C of subcooling
      - Orifice: -10 °C to 10 °C of superheat
   d. Electrical voltage: 80 % to 120 % of the rated voltage
   e. Expansion device mismatched: - 30 % to 30 % size
3. Climates (cooling and heating): hot-humid, hot-dry, mixed, and heating dominated
4. Single-family houses: house on a slab, house with a basement (the structures must be representative for the climate).

Tasks to be undertaken are delineated below.

Task 1: Critical Literature Survey. Literature review and critical analysis of the results from the related research to secure qualitative and quantitative impacts of various deviations from a fault-free commissioning and to determine the best method for modelling the building/heat pump system at different fault levels.

Several studies on degradation of the air conditioner and heat pump performance due to different faults are documented in the literature. While in most cases the main interest of these studies was the fault detection and diagnosis, the findings can be used in the analysis of impacts of faulty installation. The reports by Kim et al. (2006) and Payne et al. (2009) present a literature review up to the dates these reports were published and a substantial amount of laboratory test data for the cooling and heating mode, respectively. The range of the studied faults, however, does not completely cover the range of installation faults of interest, and will have to be extended through controlled laboratory experiments in environmental chambers.

The public domain also includes simulation studies of building/heat pump systems. These studies have been most often concerned with the analysis of energy consumption of improperly charged air conditioners. For example, Sachs et al. (2009) used TRNSYS (2004) to explore the impact of various faults on seasonal air conditioner performance. Hourly simulations were used to examine a reference house in 11 climates. The impact of over and under charging for both thermostatic expansion valve (TXV) and orifice systems was evaluated. Other impacts such as duct leaks, high static, and fan motor efficiency were also studied. The combined impact of multiple faults was not analyzed, and the heating performance was not in the scope of the study. The up-to-date literature review will be completed and documented by April 2011.

Task 2: Identify Sensitivity Parameters. Based on review of the available experimental data, a plan for fault-free and faulty heat pump tests will be developed to satisfy the stated scope of the project for all important QI parameters. The test results will be used to develop correlations of heat pump performance degradation due to “commissioning faults” for inclusion in building/heat pump simulations.

Task 3: Modelling and/or Laboratory Controlled Measurements. Models of house-on-slab and house-with-basement structures will be developed for each of the four climates used in this study. These models will include the capability to simulate leaky ducts and room-to-room air flow misbalance. The models will be validated against available data.

Task 4: Simulations of Seasonal Impacts. Building/heat pump seasonal simulations will be performed for the cooling and heating modes, for single faults at three fault levels and for selected multiple faults, for two building structures in four US climates.

Task 5: Report and Information Dissemination. The final report will cover the individual tasks and will include an analysis of performance degradation when installation practices deviate form those stipulated by ACCA QI Standard (ANSI/ACCA 2010]. This report will also address the viability and impact of varied measurement methods (instrumentation, procedures, etc.) on cost-effectively undertaking various QI measurements (e.g., refrigerant charge, airflow, duct leakage, etc.)

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