Ongoing Annexes

IEA HPP Annex 36 Quality Installation / Quality Maintenance Sensitivity Studies

(Avoiding Heat Pump Efficiency Degradation Due to Poor Installations and Maintenance)

SUMMARY ARTICLE

Introduction

It is widely recognized that residential and commercial heat pump equipment experience significant "in-field" performance loss (i.e., capacity and efficiency) depending on how the components are sized, matched, installed, and subsequently field-maintained. However, the extent and degree to which design, installation, and maintenance faults impact system performance was unquantified. IEA Annex 36 evaluated how deficiencies in these areas cause heat pumps to perform inefficiently and hence waste considerable energy. Some investigations (France and UK) included field tests and assessments. Other efforts included laboratory (France, UK, US) and/or modelling work (France, UK, US), and statistical analyses of large failure databases (Sweden).

The outcome from this Annex activity clearly identifies that poorly designed, installed, and/or maintained heat pumps operate inefficiently and waste considerable energy compared to their "as-designed" potential. Additionally, it is clear that small faults for a given field-observed practice are significant, that some attribute deviations (in various equipment applications and geographical locations) have a larger impact than others, and that multiple faults or deviations have a cumulative impact on heat pump performance.

Annex 36 Objectives

The final report provides reliable information for use by key stakeholders in industry (HVACR and construction trades), government (policy makers), and the building sector (owners/operators), so that each stakeholder can take actions to ensure optimum heat pump performance. This serves to lower energy consumption – and the resultant

Table 1: Annex 36 Participants' Focus Areas and Work Emphasis

Annex 36 Participants	Focus Area	Work Emphasis
France	EdF – Space heating and water heating applications.	**Field:** Customer feedback survey on HP system installations, maintenance, and after-sales service. **Lab:** Water heating performance tests on sensitivity parameters and analysis.
Sweden	SP – Large heat pumps for multi-family and commercial buildings KTH/SVEP – Fault detection and diagnoses in heat pump systems	**Field:** SP – Literature review of operation and maintenance for larger heat pumps. Interviews with real estate companies owning heat pumps. KTH/SVEP – Investigations and statistical analysis of ~ 68 000 heat pump failures. **Modeling/Lab:** KTH – Determination of failure modes and analysis of found failures and failure statistics based on analysis of most common and costly faults reported to insurance companies and equipment manufacturers.
United Kingdom	DECC – Home heating with ground-to-water, water-to-water, air-to-water, and air-to-air systems.	**Field:** Monitor 83 domestic heat pumps and made modifications to improve performance. **Lab:** Investigate the impact of thermostatic radiator valves on heat pump system performance.
United States (Operating Agent)	NIST – Air-to-air residential heat pumps installed in residential applications (cooling and heating).	**Lab:** Cooling and heating tests, with imposed faults, to develop correlations for heat pump performance degradations due to those faults. **Modeling:** Seasonal analyses modeling to evaluate the effect of installation faults on heat pump seasonal energy consumption. Includes effect of different building type (slab vs. basement foundation) and climates in the assessment of impact of various faults on heat pump performance.

Participants
DECC → Department of Energy and Climate Change (UK)
EdF → Electricité de France
KTH → Royal Institute of Technology (Sweden)
NIST → National Institute of Standards and Technology (US)
SP → SP Technical Research Institute of Sweden
SVEP → Swedish Heat Pump Association
Annex 36 co-Operating Agents
ACCA → Air Conditioning Contractors of America (US)
NIST → National Institute of Standards and Technology (US)
ORNL → Oak Ridge National Laboratory (US)

emissions of greenhouse gases – by encouraging the observance of quality heat pump design, installation, and maintenance practices.

The Annex results position stakeholders to better understand how quality installation (QI) and quality maintenance (QM) practices beneficially impact heat pump performance.

- HVAC practitioners will be able to provide their customers with a higher quality product, delivering "as designed" efficiency throughout its service life.
- Discriminating homeowners and building owner/operators will realize enhanced comfort, reduced energy usage, improved occupant productivity, and enhanced occupant safety.
- Program managers for entities charged with minimizing energy utilization (i.e., utilities, utility commissions, energy agencies, legislative bodies, etc.) will be better able to focus attention, resources, and effort, on the important heat pump system design, installation, and maintenance parameters for different types of heat pump applications in varied geographic conditions.

Annex 36 Work Emphasis
The specific focus areas and emphasis undertaken by the participating countries are identified in Table 1. Selected findings from the individual Country reports are highlighted in the sections that follow.

FRANCE – FOCUSED PROJECTS ON HEAT PUMP SPACE HEATING AND WATER HEATING

Field Survey
A survey of 202 owners of existing units in individual houses was conducted; 78 % of the homes used air-source heat pumps (ASHPs; air-to-water or air-to-air), and 22 % used ground-source heat pumps (GSHPs). Significant findings were:

- The majority of homeowners reported that their systems provided good comfort.
- Main issues cited involved noise and comfort control; also cited was the first cost associated with a newly-installed system (for the entire sample size, the average price of a heat pump installation was 13 500 Euros).
- Two-thirds of the homeowners indicated that a maintenance contract was beneficial; maintenance contract costs ranged from 80 € to 350 €, with an average value of 144 € (there was no significant maintenance contract cost difference between ASHP and WSHP).
- Most respondents noted maintenance and energy costs to be affordable.
- Table 2 identifies frequency of failure occurrences by failure modes.

Lab and Field Testing of ASHPs
A ductless, R-410A system was tested in laboratory and field installed conditions:

- Laboratory testing indicated that a 40 % refrigerant undercharge caused the ASHP COP to drop by 18 %.
- For homes with low-load requirements, proper equipment sizing and control becomes even more important to prevent seasonal COP degradation.
- At low outdoor air temperatures (i.e., below the equipment's thermodynamic balance point), ASHPs cannot satisfy the entire heating demand and auxiliary heat was needed.

Lab and Field Testing of Heat Pump Water Heaters (HPWHs)

- HPWH installation required a two-person crew; but, there were no identified installation issues or concerns.
- Critical operating requirements were achieved; even during the winter period, when the outdoor air temperature was approximately -11 °C (12 °F).

Significant Achievement
This effort led to the development of a CO_2 HPWH tailored to the needs of the French market. The resultant system was of modular design, requiring an installation time of ½ day, and delivering an annual COP of ~3.0.

Table 2: Failure Occurrences by Failure Mode (EdF contribution)

Incident	% of total occurrences
Water or liquid leak	16%
Installation error, electrical connection error	12%
Refrigerant leak	8%
Adjustment problem	8%
Frost, ice on fan	8%
Manufacturing defect on the heat pump	6%
Failure of the electronic board	6%
Shut down of the heat pump	6%
Electrical problems: Circuit breaker "trips"	6%
Insufficient domestic hot water	4%
Filter clogged, obstructed	4%
Circulator failure	2%
Compressor failure	2%
Fan failure	2%
Failure of a heat pump component	2%
Scale deposit	2%
Difficulty in restarting the heat pump	2%
Air bubbles in the system	2%
Heat pump overheating	2%
Need to redo the drilling	2%

Table 3: Summary of the Most Common & Costliest Faults in Different Types of Heat Pump Systems (According to the reports to Heat Pump Manufacturers during 2012 – 2012; KTH contribution)

	Type of Heat Pump (HP)			
	Air-to-Air HP	Air-to-Water HP	Brine-to-Water HP	Exhaust Air HP
The most common faults	Fan (26%)	Pressure switch (44%)	Control and Electronics (31%)	Control and Electronics (32%)
	Control and Electronics (25%)	Control and Electronics (25%)	Shuttle valve (19%)	Shunt valve/motor (19%)
	Temperature Sensors (16%)	Temperature sensors (10%)	Liquid pumps (17%)	Temperature sensors (11%)
The costliest faults	Control and Electronics (23%)	Pressure switch (25%)	Control and Electronics (28%)	Control and Electronics (24%)
	Refrigerant Leakage (17%)	Control and Electronics (21%)	Liquid pumps (18%)	Refrigerant leakage (17%)
	Fan (15%)	Compressor (19%)	Shuttle valve (12%)	Domestic Hot Water tank (13%)

SWEDEN (KTH) – A COMPREHENSIVE ANALYSIS OF FAULTS IN SWEDISH HEAT PUMP SYSTEMS

Comprehensive Database

A survey was undertaken in cooperation with Folksam (one of the largest insurance companies in Sweden), and with some of the main Swedish heat pump manufacturers:

- The Folksam database tabulated 13 993 faults and included fault data from 2001 to 2011; after removing incongruent data, the number of faults included in the analysis was 8 659. The manufacturer database included 37 000 faults field-reported to the heat pump manufacturers from the beginning of 2010 to the end of 2012.
- The procedure for analyzing the two sets of data was as follows:
  - » Data were categorized according to the different types of heat pumps (i.e., air-to-air, air-to-water, brine-to-water, and exhaust air).
  - » Data were grouped into different categories by fault or failure reason.
  - » The most frequent and costliest faults reported to the insurance company, or to the heat pump manufacturers, were determined.
  - » Meetings with heat pump manufactures were held in order to review the analysis and to investigate the root cause of the faults reported.
- Statistics were assembled that reveal the most common types of faults and problems that occurred in installed Swedish residential heat pumps. This information was regrouped to identify those faults that resulted in the costliest remediation expenses.
  - » Based on the database provided by Folksam, the faults related to compressor, control and electronics, fans, and shuttle valves, were the most frequent and also the costliest to rectify.
  - » The faults reported to the insurance companies (see Table 3) were different from the ones which were reported to the OEMs from both number and cost perspectives. The reason for the difference is partly due to the difference between the age of heat pump when it is under or out of the warranty period.

Significant Achievement

Building on the faults database analyses, a 'smart fault detection & diagnostic (SFDD) system' is currently under development.

SWEDEN (SP) – OPERATION AND MAINTENANCE OF HEAT PUMPS IN APARTMENT BUILDINGS OWNED BY SMALLER PROPERTY COMPANIES

Customer Interviews and Results Analysis

SP's programme of work focused on heat pumps serving apartment buildings in Sweden, where heat pumps are used mainly for space heating and domestic hot water heating. The main result of the interviews was that heat pumps themselves are seen as reliable; that is, in terms of providing space heating and domestic hot water heating. However, the main difficulties were:

- Lack of knowledge by building service personnel of proper purchasing, design and commissioning of heat pump systems; ability to identify the requirements, and to apply a heat pump system that suits the building.
- Lack of adjustment and functional control of the whole building system at heat pump start-up.
- Lack of knowledge on how to monitor and control the heat pump system during operation.
- Interviews of heat pump owners indicated that failures on residential systems are also caused by poor quality of components, and component/system operation outside of manufacturer specified limits.

Significant Achievement
An information manual – aimed at owners of small multi-family buildings – was developed that provides guidance on purchasing, commissioning, operation & maintenance, and system monitoring for various heat pump systems.

UK – IMPROVEMENTS TO DESIGN AND INSTALLATION STANDARDS OF DOMESTIC HEAT PUMP SYSTEMS

Field Analysis and Retrofitting
A two-year effort was undertaken where the first year analyzed the site performance of 83 residential installations. The main design and installation faults found were: over-use of the electric backup heat (caused by under-sizing of the heat pump, or poor control strategies), under-sizing of the ground loop, high central heating flow temperatures (leading to poor performance), high consumption of electricity by circulation pumps on the central heating side, incorrectly sized domestic hot water tanks (leading to overuse of the electric immersion, or alternatively, wasting energy if more water is heated than the householder can use), and excessive use of defrosting (for ASHPs). Modifications ranging from major to minor were made to 38 of the heat pumps and these were retested during the second year (see Figure 1). For this investigation:

- The most common configurations were GSHPs supplying radiators and domestic hot water; albeit, ASHPs were also included in the sample.
- First year results showed rather low overall system efficiencies; 1.2 to 2.2 W/W (~1.8 mean) for the ASHPs, and 1.8 to 3.4 W/W (~2.4 mean) for the GSHPs.
- System efficiency was strongly influenced by the household's use of domestic hot water and by the heat losses from the domestic hot water cylinder / tank.
- The majority of retested systems subjected to moderate or major system interventions showed system efficiency improvements ≥0.3 W/W; that is, (heat delivered to the radiators + the heat delivered from the domestic hot water taps) / all electrical inputs including circulation pumps on both the source and sink side.

Laboratory Studies
Laboratory experiments were undertaken to analyse the effect on heat pumps from cycling, water buffer tanks, and the efficiency of hot water tanks. Findings were:

- For ASHPs: efficiency drops dramatically as the operating runtime fraction decreases.
- For GSHPs: short runtimes had less impact on system efficiency.
- Heat losses from hot water tanks increased by at least 20 percentage points as the storage temperature increases from 45 °C to 55 °C (113 °F to 131 °F).
- Including a buffer tank in the central heating circuit reduces cycling losses. This is of value when the volume of water heated is insufficient to avoid cycling, or when heat pumps are operated on a cheap tariff and heat storage is necessary.
- For optimum efficiency, the hot water storage temperature should be slightly lower than the flow temperature of the heat pump.
- Where usage is low, the hot water tank should not be heated continuously.

Significant Achievement
The investigation resulted in revisions to the heat pump system design/installation standard (i.e., Microgeneration Certification Standard MIS 3005 issue 3.1) with improved

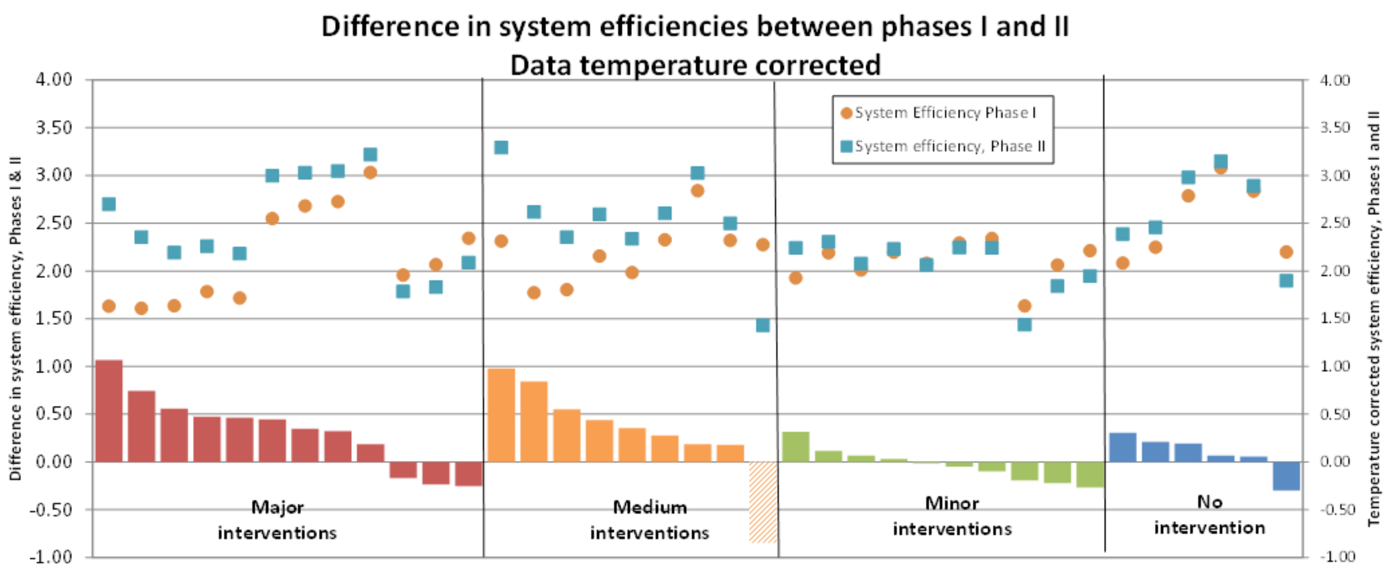

Figure 1: Difference in Temperature-Corrected System Efficiencies between Phases I and II of the Energy Saving Trust Heat Pump Field Trials (DECC Contribution)

guidance to designers, installers, and maintenance personnel. The standard provides updated sizing requirements, new guidance on heat emitter design (e.g., appropriate spacing of pipes in underfloor systems and the appropriate sizing of radiators), new information on designing ground loops and boreholes, and updated guidance on the sizing of domestic hot water tanks.

US – SENSITIVITY ANALYSIS OF INSTALLATION FAULTS ON HEAT PUMP PERFORMANCE

Laboratory Correlations

A single-speed, split-system, 8.8 kW (2.5-ton), ducted ASHP – having rated seasonal cooling and heating efficiencies of 3.81 SPFc and 2.26 SPFh, respectively (13 SEER and 7.7 HSPF) – was tested with a number of imposed fault parameters to correlate the heat pump performance degradation due to those faults. Faults investigated included improper indoor coil air flow, improper refrigerant charge, presence of non-condensible gases in refrigerant, improper electric line voltage, undersized thermal expansion valve (TXV), air duct leakage, excessive refrigerant subcooling, and improper system sizing. Most of the fault parameters were based on the requirements in the ANSI/ACCA 5 QI – 2010 Standard (HVAC Quality Installation Specification).

Simulation Studies

Annual (summer cooling and winter heating) energy simulations were undertaken (using the laboratory-derived correlations) for heat pumps installed in two, single-family, single-zone, home configurations – house with a basement (ducts and equipment located in semi-conditioned basement), and house on a slab (ducts and equipment located in the unconditioned, vented attic) – for five representative U.S. weather locations. The modeling determined the annual energy impacts of the individual fault parameters both individually and in combination.

- Air duct leakage (for attic installations) had the largest single energy impact (~ 30 % increased energy consumption), followed by refrigerant undercharging (15 % increase), oversizing with nominal sized ductwork (10 – 15 % increase), improper airflow (10 – 15 % increase), and refrigerant overcharging (10 % increase).
- Effect of different installation faults on annual energy use was similar for both the slab-on-grade and basement houses, except for the duct leakage fault.
- Effect of different installation faults was similar in all locations except for the following cases:
  - » Duct leakage: significant increase in the indoor relative humidity for an installation in a hot and humid climate.
  - » Heat pump oversizing with undersized air ducts: in heating-dominated climates, heat pump oversizing reduces the use of backup heat, which may compensate for the increased indoor fan energy use associated with undersized ducts.
  - » Undersized cooling mode TXV: little effect in heating-dominated climates, but significant increase in energy use for cooling-dominated climates.
- The effect of multiple faults is approximately additive in most cases (e.g., duct leakage coupled with refrigerant undercharging increases annual energy consumption by ~ 50 %).
- The report notes that a significant increase in annual energy use can be caused by lowering the thermostat in the cooling mode to improve indoor comfort in cases of excessive indoor humidity levels. As an example, for Houston, TX, lowering the thermostat setting by 1.1 °C (2.0 °F) increased the annual energy use by 20 %.
- The report contends that the laboratory and modeling results are representative of all unitary equipment; residential and commercial split-systems and single package units (e.g., roof top units).

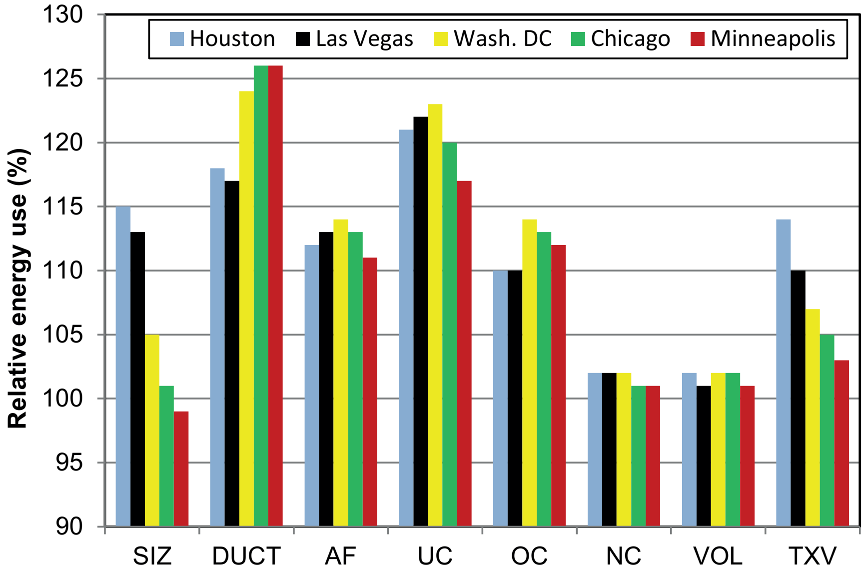

Figure 2. Annual energy use by a heat pump in a slab-on-grade house resulting from a single-fault installation, referenced to a fault-free installation. Fault levels: SIZ +50%, DUCT +30%, AF -36%, UC -30%, OC +30%, NC +10%, VOL +8%, and TXV -40%. (NIST contribution)

Significant Achievement

The laboratory investigations and modeling analyses quantified the amount of degradation experienced by air source heat pumps typically-installed in the U.S. (see Figure 2).

This information is serving as the basis for which U.S. Federal, State, and local entities are assessing their energy efficiency programs and effecting changes.

Future Needs Identified by Annex 36

As can be observed in the above overview, the types of investigations undertaken by the participating countries were very different, and the studied equipment applications were broad. However, there are a number of cross-cutting needs that universally accrue to all and are in need of future exploration:

1. Development of open communication protocols to facilitate commissioning and re-commissioning; entails a common set of error codes as well as a universal access port/method to retrieve the error codes.
2. Quantify the impacts of faults on high-efficiency, premium equipment, installed in energy-efficient, low-load structures.
3. Determine the effect of simultaneous, multiple faults / deficiencies (at different severity levels) through rigorous laboratory measurements.
4. Collect and analyze in-field fault data (type, frequency, degree of severity) to quantify the national impact of heat pump inefficiency. This could include monitoring of installed equipment to ascertain on-going efficiency.
5. Need for reliable, cost-effective means to measure heat pump capacity delivery (heating and cooling) to the conditioned space.
6. Need to quantify the effect that installation and maintenance deficiencies have on occupant comfort / health, equipment reliability / robustness / maintainability, and operational / maintenance costs.
7. Investigate energy efficient methods for controlling bacteria such as Legionella in domestic hot water applications.
8. Information on installation rules and maintenance procedures needs to be created and provided in a manner that installers and service personnel (and owners) can easily understand and implement.
9. Approaches to improve communications and cooperation among the various stakeholders (manufacturers, distributors, customers, insurance companies, efficiency programs, etc.) to ensure that incentives, encouragements, and rewards, result in quality equipment being purchased with installations and maintenance undertaken by trained, qualified service personal.

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