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IN THIS ISSUE:

Impact of installation faults on HP performance

Improved reliability of residential HP's in Sweden

Two new Annexes presented

IEA HEAT PUMP CENTRE

NEWSLETTER
VOL. 33
NO. 1/2015

Quality installation / Quality maintenance

Heat Pumps - A key technology for the future

IEA **Heat Pump** CENTRE
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In this issue

Heat Pump Centre Newsletter, 1/2015
A heat pump is an impressive tool for upgrading heat from a source, to usable temperatures. However, in order for it to work as intended, proper installation and maintenance is necessary. Further, any deficiencies in these may add up, or even synergistically give rise to larger problems.

In this issue we take a look at heat pump installation and maintenance, which has been the subject of Annex 36. The Foreword, by the Operating agents of Annex 36, gives the background. Of the two topical articles, one describes experiments and analysis of these issues, while the other looks at actual reported problems from real installations.

Enjoy your reading!

Johan Berg, Editor

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Foreword

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Quality Installation and Quality Maintenance for Heat Pump Systems

A significant opportunity for improving heat pump operating performance (capacity, efficiency, etc.) is related to how well the cooling and/or heating equipment is installed and subsequently maintained in different building applications. A major challenge to promoting proper installation and maintenance is that the marketplace tends to incentivize 'cutting corners' to reduce first-cost. This results in equipment installations with poor performance and poor value to the end-user. Generally, an underlying cause of this predicament is that industry participants (e.g., manufacturers, distributors, designers, installers, etc.) and end users (e.g., building owners, operators, and customers) do not appreciate the impact of cumulative installation and maintenance deficiencies on system performance.

Some common installation and maintenance deficiencies for heat pumps include:

- oversizing,
- improper refrigerant charge,
- incorrect airflow over the indoor heat exchanger,
- incorrect water flow through the indoor (load side) hydronic heat exchanger,
- malfunctioning hydronic system control valves, and
- leaky air distribution ducts.

However, the heating, ventilation, and air-conditioning (HVAC) industry lacked good, quantitative information on the relative value and importance of varied field installation / maintenance practices and the effect that deficiencies may cause.

In 2010, the IEA HPP Annex 36 was initiated to investigate a wide range of heat pump faults commonly found in operating equipment, including those listed above. The participants – France, Sweden, The United Kingdom, and The United States – evaluated how deficiencies in these areas cause heat pumps to perform inefficiently and hence waste considerable energy. Investigations included field tests and assessments (France and UK), laboratory and/or modelling work (France, UK, US), and statistical analyses of large failure databases (Sweden).

Prior to the undertaking of Annex 36, earlier investigations examined existing equipment in the field and the impact that corrective measures may provide, but provided only limited quantifiable information on the impact of these measures on equipment performance. The outcome from this Annex activity clearly identifies that poorly installed and/or maintained heat pumps waste considerable energy compared to their "as-designed" potential. It is clear that even small faults for given field-observed practices can be quite significant, that some faults (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.

Topical articles in this issue includes two from Annex 36 participants, summarizing specific findings of the Annex.

Column

IEA HPP contributes to raising the deployment of heat pumping technologies

Stephan Renz
Chairman,
Executive Committee (ExCo)
of the Heat Pump Programme

Heat Pumping technologies must play a major role in the future sustainable energy system. They help to increase energy efficiency, to raise the use of renewable energies and to reduce greenhouse gases. In most of thermal energy conversion and supply processes – i.e., both above and below ambient temperature – heat pumping technologies are applicable and show a better efficiency than other technologies. Much work is needed in order to increase deployment of heat pumps, to improve their efficiency, to widen their field of application, to disseminate knowledge about this technology, or to optimise integration of heat pumps with additive energy systems such as solar thermal or photovoltaic plants or connection with smart grids or district heating systems. The Implementing Agreement for a Programme of Research and Development on Heat Pumping Technologies from the International Energy Agency (IEA HPT IA) is aware of these challenges and helps to overcome them. IEA HPP contributes to a broad variety of R&D activities, while its dissemination of information is even assisting different fields of technology development in an international context.

It is my honour to be the Chairman of the Executive Committee of this international group of highly qualified experts, and to support their successful work.

There are several benefits to being a member of the IEA HPP. (1) You allow and support the work of the experts and researchers, both from academia and from industry, in the different project groups (Annexes) and in the Heat Pump Centre, and help to produce and disseminate improved knowledge about heat pumps in an international context. (2) You receive a lot of first-hand information and can exchange knowledge with highly qualified scientist from all over the world. And, perhaps most importantly, (3) you open doors for scientists and researchers from your country to collaborate with other specialists from a range of currently fifteen countries from Asia, North America and Europe. I would like to express my thanks to those countries and their representatives, who have for many years contributed to the success of IEA HPP!

Over the last year our work has been concentrated on supplying heat for space heating, hot water production and industrial applications. In the future we intend to expand our activities and include more projects related to air conditioning (cooling) and refrigeration. This should be of interest for countries in regions with warmer climates and an increasing energy demand.

To maintain the high quality of our results, it will be necessary to tighten the work in the annexes and to minimise overlaps. Spreading information on heat pumps must be continuously improved and employ new methods. Particularly important deliverables are the annual National Team meetings, the work in and reports from the Annexes, the HPC Newsletter and the Heat Pump Conference. After a successful conference in Montreal in 2014, we will soon announce the next conference, to be held in 2017. We are looking forward to a very interesting programme to attract many delegates from all over the world and to spread our message: Heat pumping technologies must play a major role in future sustainable energy systems.

General

AREA presents its Vision & Strategy 2020

AREA, the European organisation of air conditioning, refrigeration and heat pump contractors, has published its Vision & Strategy 2020, identifying six key areas for a striving refrigeration, air conditioning and heat pump (RACHP) contracting sector.
Constant technological evolutions and recent regulatory changes are reshaping the (RACHP) sector. According to AREA, the challenge for contractors is to embrace these developments whilst maintaining excellence.
AREA President Per Jonasson said: "Innovations and regulations make refrigeration and air conditioning more exciting, but also more complex. Users rely on expert contractors more than ever."

AREA has identified six key priorities:

1. Sensible standards and regulations that support rather than obstruct the sector's development;
2. Minimum education and certification requirements on low-GWP refrigerants to ensure safe and competent handling
3. Energy efficiency as a key driver in refrigerant and system choice
4. Guidance on technological developments to ensure up-to-date knowledge
5. Exchange of information and best practices within the sector through the AREA network
6. European and international cooperation at both industrial and institutional levels

AREA's Vision & Strategy 2020 can be downloaded from its website at *http://www.area-eur.be*.

Source: www.acr-news.com

Policy

ASHRAE/IES proposes expansion of climate zones

New proposed climate data could make the ASHRAE/IES energy standard more applicable for global use. Addendum *w* is one of ten proposed addenda to ANSI/ASHRAE/IES Standard 90.1-2013, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. The addendum was developed in response to an update of ASHRAE Standard 169-2013, *Climatic Data for Building Design Standards*, which now contains updated climate data and additional Climate Zone 0 with humid (0A) and dry (0B) zones. Addendum *w* adds this climate zone to 90.1. This has global implications for the standard, as Climate Zone 0 does not exist in the United States and is primarily used in the equatorial regions of South America, Africa, Middle East, southern Asia and the south Pacific.

Source: www.ashrae.org

India and US agree to make progress on HFCs in 2015

In a meeting held on 25-26 January 2015, the US President and Indian Prime Minister reaffirmed their commitment to work on phasing down hydrofluorocarbons (HFCs) under the Montreal Protocol, and to make progress in negotiations this year. While China had already relaxed its opposition in earlier meetings, India's changing stance is instrumental in opening up the negotiations on the HFC amendment under the Montreal Protocol.
The agreement to make progress on the reduction of HFCs in the Montreal Protocol has been generally applauded as a breakthrough. The two countries recognise the need to use the institutions and expertise of the Montreal Protocol to reduce consumption and production of HFCs. They also pledged to initiate bilateral meetings to discuss issues related to safety, cost and commercial access to new or alternative technologies to replace HFCs.
Energy-efficient and low-carbon air conditioning is essential for India's hot climate. The US and India agreed to work together on improving the efficiency of India's cooling sector. To this end, the US will develop a so-called Advanced Cooling Challenge to catalyse the development of super-efficient, climate-friendly and cost-effective cooling solutions for India.

Source: www.r744.com

EHPA: Policy sometimes contradicts itself

In five years from now, we will wish each other a happy new year 2020 and, after the celebrations are done, there will be time to assess where we stand with the 2020 targets. Most likely, the GHG reduction target will be reached, the RES target may be, but we will hardly have achieved a 20 % reduction in final energy demand. It is surprising that, on the one hand, energy efficiency is and has been cited as the low-hanging fruit. Good for society by leading to lower energy cost and keeping purchasing power local, thus maintaining affordability of energy supply and supply security as well as generating employment. Good for the environment in general, by replacing watts produced with megawatts saved and so also reducing production, transport and use-related pollution. Good for the atmosphere in particular, by avoiding fossil fuel-based emissions.

On the other hand, it seems to be nearly impossible to create a market framework that triggers consumer behaviour in the corresponding direction. Fossil fuels are still cheap for various reasons, the most astounding one being that many governments directly or indirectly still subsidize their use.

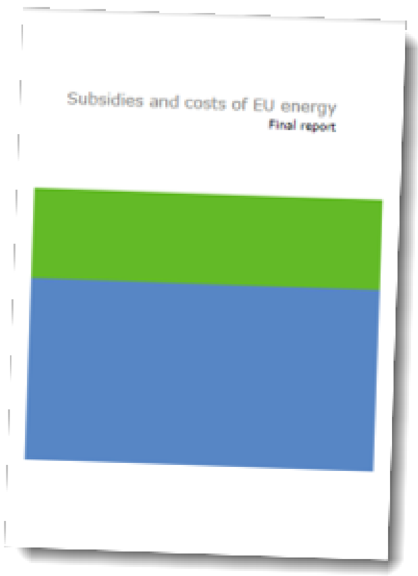
In a market reality, a new product requires an investment, and an investment is expected to pay back over time. Usually savings in operating cost or other benefits from the use of the investment have to provide this payback. In today's time of cheap fossil fuels, the payback point may not be reached.

Yet not all is lost. On a policy level, we see strong efforts to create an energy union as an overarching umbrella for Europe's climate and energy policy. Energy used for heating will receive particular attention in 2015. The year will kick off with a high level Commission event on heating and cooling, and will follow up with a number of important fairs and exhibitions, and will eventually see the introduction of energy labels for heaters into the market.

The January edition of the EHPA Newsletter sheds light on energy efficiency with a specific focus on its use in non-domestic applications.

Source: www.ehpa.org

EGEC: Geothermal is key in achieving an affordable energy transition, but lacks adequate support



The European Commission recently released a report "*Subsidies and Costs of EU Energy*", unveiling for the first time data on costs and subsidies across various generation technologies in the electricity sector in all EU member states. EGEC welcomes the release of this timely study and is pleased with the transparent debate and consultation of the relevant stakeholders that was carried out by the European Commission during the preparatory work. The geothermal sector is all the more ready to deploy new innovative technologies and to take an active part in the energy transition in Europe.

Unfortunately, the support dedicated to geothermal energy in the EU is negligible compared to other power generation technologies. In 2012, geothermal only received €70 million, compared to €14.7 billion for solar PV and €6.6 billion for nuclear! Geothermal cannot live up to its promises without adequate support.

EGEC therefore calls for the swift rebalancing of support across all power generation technologies.

Source: www.egec.info

Working fluids

2015 - critical year for refrigerant substitution in China

A seminar on low-carbon refrigerant substitution technology, organised by the Foreign Economic Cooperation Office (FECO) of the Ministry of Environmental Protection and co-organised by China Refrigeration and Air-Conditioning Industry Association (CRAA), was held in December in Beijing. Over 200 participants, including officials from the Ministry of Environmental Protection, representatives from the refrigeration industries, refrigerant manufacturers and research institutes, attended the seminar. According to FECO, year 2015 will be critical for refrigerant substitution since HCFCs are scheduled to be phased down by 10 % by the end of 2015, and low-carbon refrigerants such as R32 and CO_2 are entering the market.

FECO pointed out that the industrial and commercial AC&R industries in China are required to phase out 8450 tons of HCFCs consumption by the end of 2015. Although large enterprises have participated in the phase-out program, small companies are still reluctant to do so. In 2015, the Ministry of Environmental Protection will raise the subsidies for natural refrigerants such as NH_3 and CO_2, push forward the restructuring of R32 scroll compressor production lines, and promote R32 technology and products.

Source: www.ejarn.com and *JARN, January 25, 2015*

Technology

VRF Systems and Testing Towers

When VRF systems were released in Japan in the second half of the 1980s, the maximum height difference between the indoor and outdoor units of single split packaged air conditioners able to be connected by piping was about 50 meters, which complied with Japan's Building Standard Law. In those days, there was no way to confirm the height difference between indoor and outdoor units until after the units were actually installed in the building. It was also impossible to perform tests that manipulated the indoor and outdoor temperatures. In the case of simple systems in small- and medium-sized buildings that used a small number of units, it was easy enough to confirm the height difference in the field. If a problem arose after the units were installed, steps to remedy the situation could be taken in the field.

However, VRF systems are now used around the world and adopted in large-sized buildings as well. Higher levels of performance and controls are also in demand. The volume of shipments has increased exponentially, and researchers have taken an interest in the systems. To satisfy researchers , performance under various temperature conditions needs to be verified using rigorous testing room conditions. Under these circumstances, a number of VRF system manufacturers have constructed environmental testing rooms and high-rise test towers able to accommodate the maximum refrigerant piping height difference.

What's the effect of the height difference on the refrigeration cycle? In the case of heat pumps, refrigerant starts as a liquid and returns as a gas during cooling operation, and starts as a gas and returns as a liquid during heating operation. Although refrigerant in a liquid state flows slowly and experiences little pressure loss, the head pressure becomes greater when there is a large height difference, and affects the refrigerant pressure. Conversely, refrigerant in a gaseous state experiences a large pressure loss but the head pressure is small. When the piping length is simply longer without a height difference, pressure loss occurs due to the flow velocity but there is no head pressure. Taking these factors into consideration, expansion valves on the indoor and outdoor units must be designed to prevent refrigerant from migrating into lubricating oil, maintain stable refrigerant flow, and closely control expansion valve opening to ensure sufficient capacity.

In the case of VRF systems with many indoor units connected to one outdoor unit, when an expansion valve in one indoor unit is opened wider to deliver greater capacity, it is necessary to control the expansion valve openings in the other indoor units so that a sufficient amount of refrigerant is delivered while increasing the operating capacity of the compressor. Thus, complex control of the entire system becomes necessary, which has been made possible by system monitoring of large numbers of sensor readings.

While simple performance simulations are possible to a certain extent, it is virtually impossible to perform simulations of preventing refrigerant migration into lubricating oil to ensure product reliability. In reality, manufacturers' performance data on piping lengths and height differences between indoor and outdoor units and variable-capacity characteristics differ widely, and a generally accepted theoretical framework has not yet been realised.

For these reasons, verifying performance data obtained in experiments using tower testing rooms is needed to facilitate constructing a generally accepted theoretical framework.

Source: JARN, January 25, 2015

Markets

Growth in heat-pump sales volumes in Finland

67 000 heat pumps were sold last year in the country of five million people. This represented a growth of 10 % as compared to the previous year. The market share growth in energy-efficiency refurbishment, as well as the warm summer, increased air-source and air-to-water heat pump sales. The strong decline in construction brought the ground-source and exhaust air heat pump figures down. The 670 000 heat pumps draw 5 TWh worth of local heat from around buildings annually. Finns invested approximately 400 million Euros in heat pumps in 2014.

Air-to-water and air-source heat pump sales grew by 15 %. As many as 53 000 air-source heat pumps were sold. This was partly due to the warm summer last year, which drew attention to the capacity that heat pumps also provide in the form of cool relief to a hot building. The strong decline in construction brought the ground-source and exhaust air heat pump figures down. The sales figures of geothermal heat fell by 10 % to just over 11 000 pumps. However, the market shares of heat pumps have continued to grow. Already more than 50 % of constructors choose a ground-source or exhaust air heat pump solution. Approximately 6000 oil-fired boilers were replaced last year by eco-friendly ground-source heat pumps, or the oil consumption of the boilers was reduced with air-to-water heat pumps.

Finns already invest as much as 400 million Euros in heat pumps annually. The reason goes without saying: generally, the return on investment is more than 10 % per year. The impact of saved fuel on the Finnish trade balance is already in the region of one hundred million EUR. The heat-pump industry already offers employment for approximately 2000 people. Furthermore, the reduction in CO_2 emissions is in the region of a megatonne, with the

670 000 heat pumps in Finland gathering 5 TWh/a of local energy from around buildings from the ground, the bedrock or from the air – Executive Director Jussi Hirvonen says enthusiastically, as he introduces the Finnish Heat Pump Association statistics for 2014.
The good news was that finally, exhaust air heat pumps in apartment buildings also began to be more common. As many as a few hundred apartment buildings were fitted with a heat pump that captures the heat of exhaust air, which reduces as much as 50 % of district-heating or other energy expenditure of the buildings.

Source: www.ehpa.org and www.sulpu.fi

The role of industrial heat pump applications

An interview from Mr. Paul Hodson, Head of Unit of Energy Efficiency, EU DG Energy explaining what is the contribution potential of industrial applications to energy and climate as well as the energy efficiency targets.

1. *How important do you think that energy efficiency and the use of renewables are in industrial applications?* Industrial heat can be divided into three categories, depending on the necessary temperature. Processes using heat above 400 °C represent 57 % of the total industry heat consumption, while low-temperature heat demand (up to 100 °C) represents 25 % of the total industrial demand. The rest of heat is used in medium-temperature processes (between 100 °C and 400 °C). From a technological point of view, heat pumps are well placed to be used in low temperature applications. Although fossil fuels will still be necessary for some industrial processes, renewable energy can also play a role in applications with higher temperature needs if solid biomass or biogas is used.

2. *What are the key priorities of the energy policy agenda for 2015? Are large heat pump applications one of the priorities of the DG Energy's agenda?* Building an Energy Union will be at the top of the political agenda. The Energy Union must address the objectives of competitiveness, security of supply and sustainability. The recipe for this is to take forward European energy policy, in particular in the following key areas.

    - Completion of the internal energy market.
    - Enhancing security of energy supply, based on solidarity and trust.
    - Moderating our energy demand through energy efficiency, and moving forward with decarbonisation of our energy mix, including by a more effective Research and Innovation policy.

    Decarbonisation should be one of the pillars of the Energy Union. In this respect, the agreement on the 2030 Framework regarding energy and climate objectives has now to be put into effect.
    In consequence, energy efficiency will be at the top of the agenda, the deployment of heat pumps, including large heat pump applications, are part of the energy efficiency policies both from an innovation and an implementation point of view.

3. *Policy implementation is very often hindered by lack of know-how and/or financial resources. Will the European Commission address this issue by organising programs on capacity building and the provision of financial support?* Under our Horizon 2020 Energy Efficiency Work programme, important emphasis is given to supporting capacity building across the board, encompassing issues related to technology use, organisational and financial innovation, implementation of legislative framework and networking. This strand of the EU support will continue in the future. The Horizon 2020 programme also offers support for technology development and implementation, including heat pumps.

    As regards the EU financial support for investments, the Multi-Annual Financial Framework 2014-2020 significantly increases allocations for energy efficiency, in particular under European Structural and Investment Funds (EUR 17 billion expected). Further, recent Communication on "Investment Plan for Europe" proposes to establish a special "European Fund for Strategic Investments", whereas Energy Efficiency is expected to become one of its main areas of operation.

Source: www.ehpa.org

2015 ASHRAE Winter Conference Summary

ASHRAE's 2015 Winter Conference was held in Chicago, IL. It was held with AHRI Expo which has 62 000 attendances and about 2 100 exhibiting companies. The technical program took place from January 25 to 28.

This year's winter meeting had a large number of participants for the conference as well as the Expo. A lot of work is going on for low-GWP refrigerants. Several presentations covered VRF systems, net-zero energy, and field testing of various equipment. There was a high presence of microchannel evaporators in the Expo.

The Conference features papers and programs for eight tracks as follows:

- Systems and Equipment
- Fundamentals and Applications
- Industrial Facilities: manufacturing and processes can have some special requirements for HVAC&R.
- Large Buildings: Mission-Critical Facilities and Applications: Facilities such as data centers have some special characteristics.
- Energy Efficiency
- Life Safety: This encompasses egress, sprinklers, alarms, emergency lighting, smoke barriers, and special hazard protection.
- Design of Energy and Water-Efficient Systems: the trend is towards green sustainable buildings.
- Hospital Design and Codes

Some selected presentations are summarised:

Conference Paper Session 2: HVAC Refrigerants
A Historical Perspective of Refrigerant Chemical Stability and Materials Compatibility for HVAC&R Systems (CH-15-C006), by Steve Kujak

The four generations of refrigerants in HVAC&R industry are discussed: a) first generation (whatever worked): NH_3, CO_2, hydrocarbons; b) second generation (safety and chemical stability): NH_3, CFCs; c) third generation (ozone depletion concern): NH_3, HCFCs, HFCs; d) fourth generation (global warming potential): NH_3, low-GWP HCFCs and HFOs, CO_2, HCs. Numerous studies indicate that while the HFOs may be, at times, slightly less stable than some HFCs, these studies also indicate that the HFO chemistries are more stable than the CFC and HCFC chemistries, which should allow for good HVACR reliability.

Chemical Compatibility of Low GWP Refrigerants with HVAC&R System Materials (CH-15-C005), by Elyse Sorenson

This paper summarises chemical stability evaluations of unsaturated hydrofluorocarbon (HFO) refrigerants blended with R-32, which were conducted in order better to understand equipment reliability risks associated with the use of next-generation low global-warming potential (GWP) refrigerant candidates. It was found that the low-GWP refrigerant blends exhibited similar chemical compatibility with many commonly used materials as compared to R-134a. Relative to chemically stable HFC refrigerants such as R-134a, an increased risk of chemical compatibility concerns is presented by the use of new low GWP refrigerants.

Chemical reactions or chemical interaction between refrigerant, lubricants and construction are studied. Most importantly, for HVAC systems, is a stable pair of refrigerant and lubricant. Low-pressure olefin has better chemical stability than CFD and HCFC. Medium-pressure olefins have some instability; R1234yf is not as stable as R134a (HFCs). Materials containing high moisture contents showed significant fluoride concentration. There is a risk of reactivity from contaminants such as moisture.

Conference Paper Session 7: A Paradigm Shift for HVAC Design 2. Energy Modelling Multifamily Buildings: A Case Study of Prediction Versus Reality (CH-15-C025), by Sharon Gould

This paper follows two ENERGY STAR® multifamily buildings located in Madison, Wis., from design and energy modelling through two years of accumulated utility bill data. Each building is following EPA-modified ANSI/ASHRAE/IES Standard 90.1-2004. An analysis of the comprehensive utility data received for these buildings allows for a unique comparison of the buildings' energy consumption to the building design as modelled. The modelling results for this program compare well to the bills and provide a good tool for energy estimates based on the level of detail and keeping the model simple.

Conference Paper Session 8: Using Solar to Improve Efficiency Experimental Investigation of an Innovative HVAC System with Integrated PVT and PCM Thermal Storage for a Net-Zero Energy Retrofitted House (CH-15-C028), by Massimo Fiorentini

This paper presents the experimental investigation of a novel solar-assisted HVAC system developed for the Team UOW Solar Decathlon house, the overall winner of the Solar Decathlon China 2013 competition. This novel HVAC system consists of an air-based photovoltaic/thermal (PVT) system and a phase-change material (PCM) thermal storage unit, integrated with a ducted system with a reverse-cycle heat pump. The system has been designed for operation during both winter and summer, using daytime solar radiation and night sky radiative cooling to increase the energy efficiency of the air-conditioning system. The results showed that when heating the house directly, on a typical winter day, using the PVT system, this solar-assisted HVAC system was capable of achieving a significantly higher efficiency than a commercial air conditioning system, providing 12.9 kWh with an average COP of 13.5. The PVT showed a good performance, also heating a PCM thermal energy storage unit, storing 26.6 kWh with an average COP of 10.7.

Source: Selected from a report by Yunho Hwang of University of Maryland, USA

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

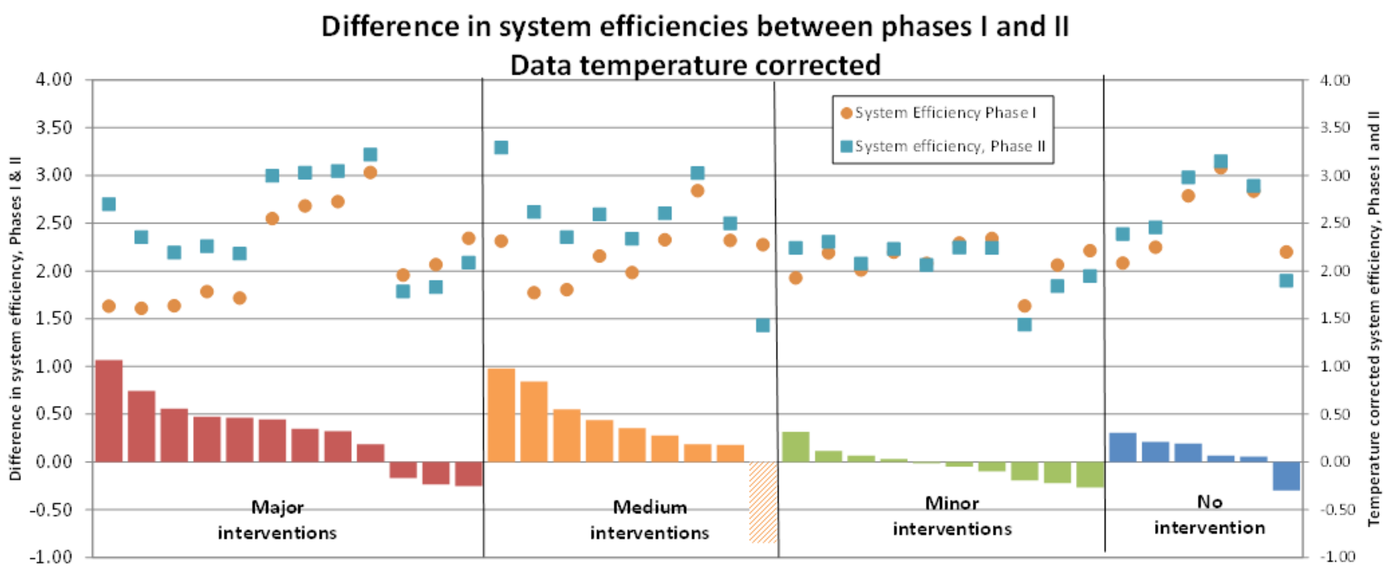


Figure 1: Difference in Temperature-Corrected System Efficiencies between Phases I and II of the Energy Saving Trust Heat Pump Field Trials (DECC Contribution)

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.

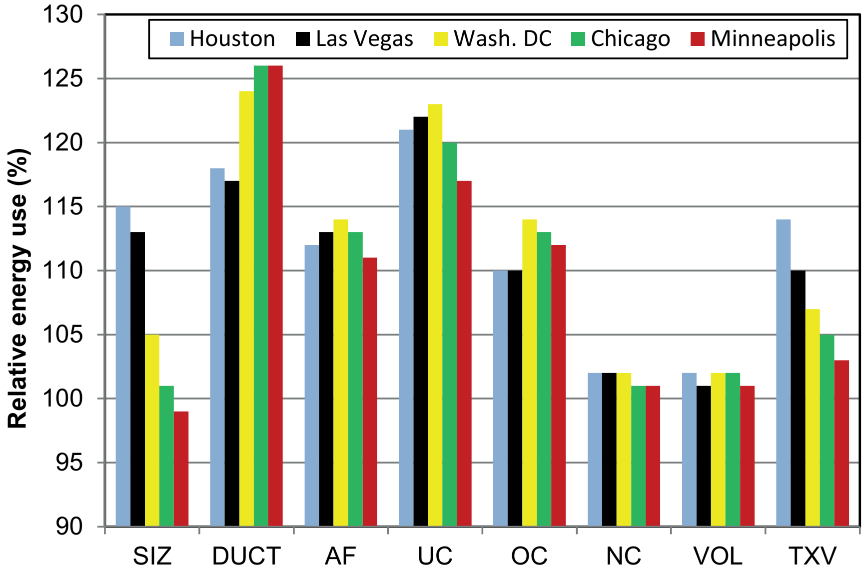


Figure 2. Annual energy use by a heat pump in a slab-on-grade house resulting from a single-fault installation, referenced to a fault-free installation. Fault levels: SIZ +50%, DUCT +30%, AF -36%, UC -30%, OC +30%, NC +10%, VOL +8%, and TXV -40%. (NIST contribution)

- 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).

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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IEA HPP Annex 40 Heat pump concepts for Nearly Zero Energy Buildings

National contributions to IEA HPP Annex 40, Task 2 and Task 3

IEA HPP Annex 40 is to investigate and improve heat pump systems applied in Nearly or Net Zero Energy Buildings (nZEB). Currently, nine countries CA, CH, DE, FI, JP, NL, NO, SE and US, are collaborating in Annex 40.

Task 2 is concerned with system comparison and improvement in terms of performance and cost. Different simulation studies are being carried out. In Switzerland, heat pumps in combination with PV for the nZEB balance are among the most cost-effective solutions in both single and multi-family buildings. It is also one of the most common systems in nZEBs that have been built. Currently, integrated systems are being investigated. In Japan, a case study for nZEB office buildings is being carried out for both Japanese and European boundary conditions. Sweden has proven by simulation work that ground-source heat pumps are a viable solution in nZEB in the Nordic climate regarding cost, and Finland is currently evaluating solutions for both single and multi-family residential buildings,

Annex 40. Powerhouse Kjørbo - the world's most environmental friendly office building [Source: Justo Alonso, Powerhouse Kjorbo_ParkLife]

including their application in retrofit buildings. Norway, on the other hand, is working on a software tool for the design of bivalent heat pump configurations in nZEB to optimise system cost and CO_2 emissions. The USA is developing a simulation tool for comfort evaluation of radiant emission systems, which is also extended to convective heating and cooling solutions.

Task 3 is dedicated to technology developments and field monitoring. Different field tests have started in 2014. In Norway, the first nZEBs are in monitoring since 2014. These buildings are among the first nZEB in Scandinavia. The US has ongoing field tests of a residential testing facility for nZEB system technology (NZERTF) and different highly integrated heat pump arrangements. The Netherlands is currently evaluating a large field test under the name of "Energy Leap", where different heating technologies (including retrofit solutions) are being evaluated. Germany has a long-term monitoring project of nZEB office buildings with heat pumps and thermally-activated building systems (TABS), and is evaluating performance and options for load management.

Interim results for Task 2 and Task 3 have been presented at two workshops in 2014.

The meeting was concluded with a half-day workshop for the exchange of Annex 40 interim results with nZEB activities of Japanese manufacturers and stakeholders.
All workshop presentations are available for download on the Annex 40 website at *http://www.annex40.net*.

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IEA HPP Annex 41 Cold Climate Heat Pumps

Annex 41 began in July 2012 to revisit research and development work in different countries to examine technology improvements leading to successful heat pump experience in cold regions. The primary focus is on electrically driven air-source heat pumps (ASHP) with air (air-to-air HP) or hydronic (air-to-water HP) heating systems, since these products suffer severe loss of heating capacity and efficiency at lower outdoor temperatures. The main outcome of this Annex is expected to be information-sharing on viable means to improve ASHP performance under cold (≤ -7 °C) ambient temperatures.

In the past quarter the co-Operating Agents completed a draft summary interim report for the Annex (including Task 1 and 2 works through about August 2014). The draft interim report has been reviewed by the Participants and revised based on those reviews. It will be posted to the Annex web site in early 2015. As reported in 2014 Newsletter issue 3, the Participants agreed at the Montréal workshop and business meeting (May 2014) to an extension of the Annex work period to allow all Participants time to complete their planned contributions. The HPP Executive Committee approved an extension of the Annex through July 2016 at its Nov. 2014 meeting. Planning is underway for the 3rd working meeting to be held May 7-8, 2015 in Vienna at the Austrian Institute of Technology. The 2nd workshop is to be held August 2015 in Yokohama, Japan during the 2015 International Congress of Refrigeration – planning of the workshop program has started.

The Annex web site is *http://web.ornl.gov/sci/ees/etsd/btric/usnt/QiQmAnnex/indexAnnex41.shtml*

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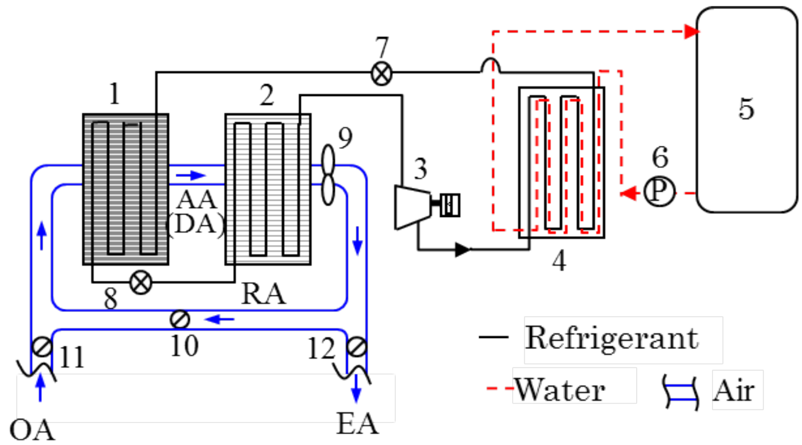
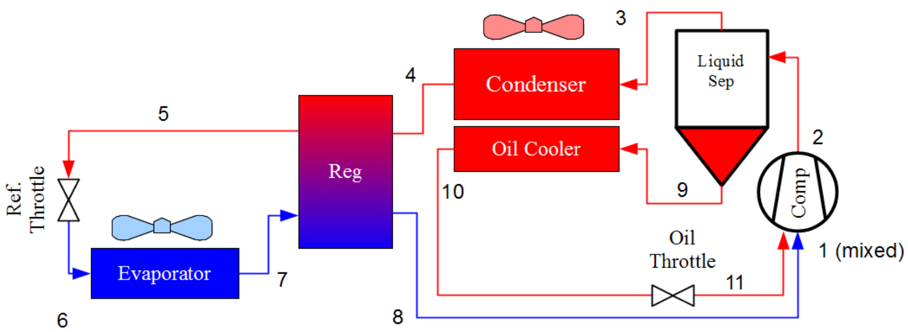
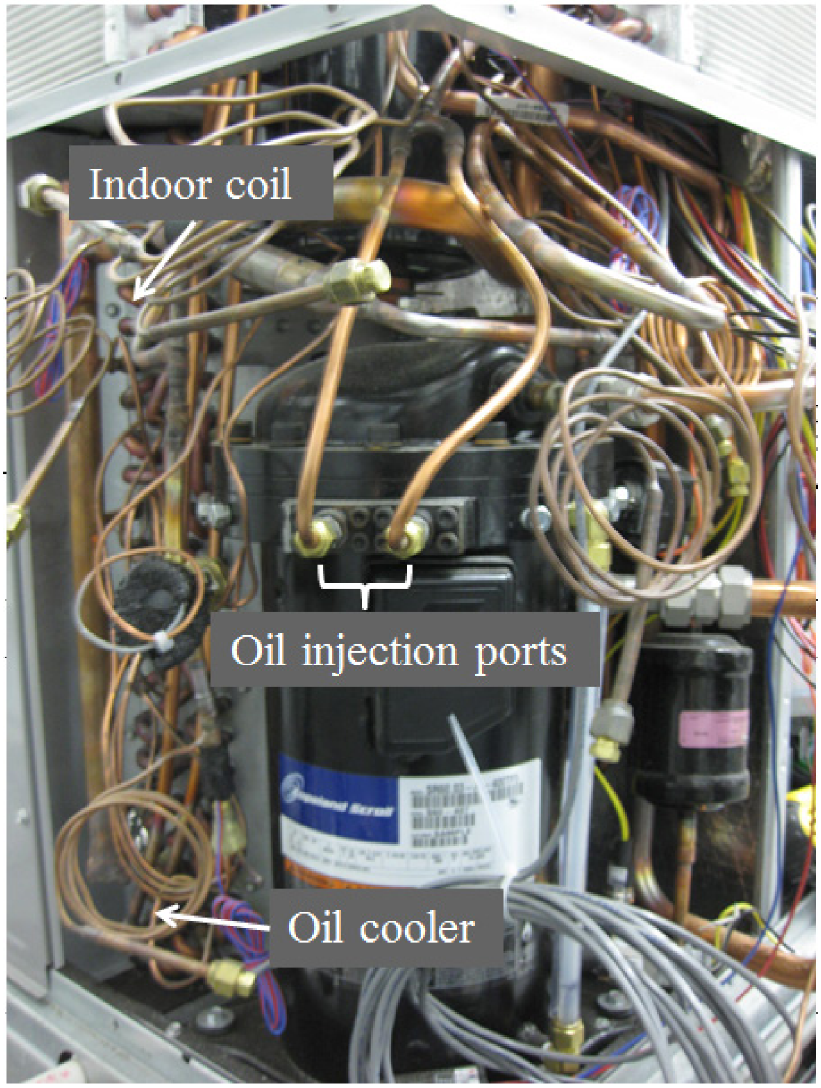


(1) Desiccant-coated heat exhanger, (2) Air heat exhanger, (3) Compressor, (4) Water heat exchanger, (5) Water storage tank, (6) Pump, (7-8) Expansion valves, (9) Fan, (10-12) Valves

Annex 41: Schematic diagram of frost-free air-source heat pump water heating (ASHPWH) system under investigation by researchers at the Central Research Institute of the Electric Power Industry (CRIEPI) of Japan





Annex 41: Oil-flooded compressor heat pump cycle concept to approach isothermal compression – schematic (above) and test system at Purdue Herrick Laboratories (below).

IEA HPP Annex 42 Heat Pumps in Smart Grids

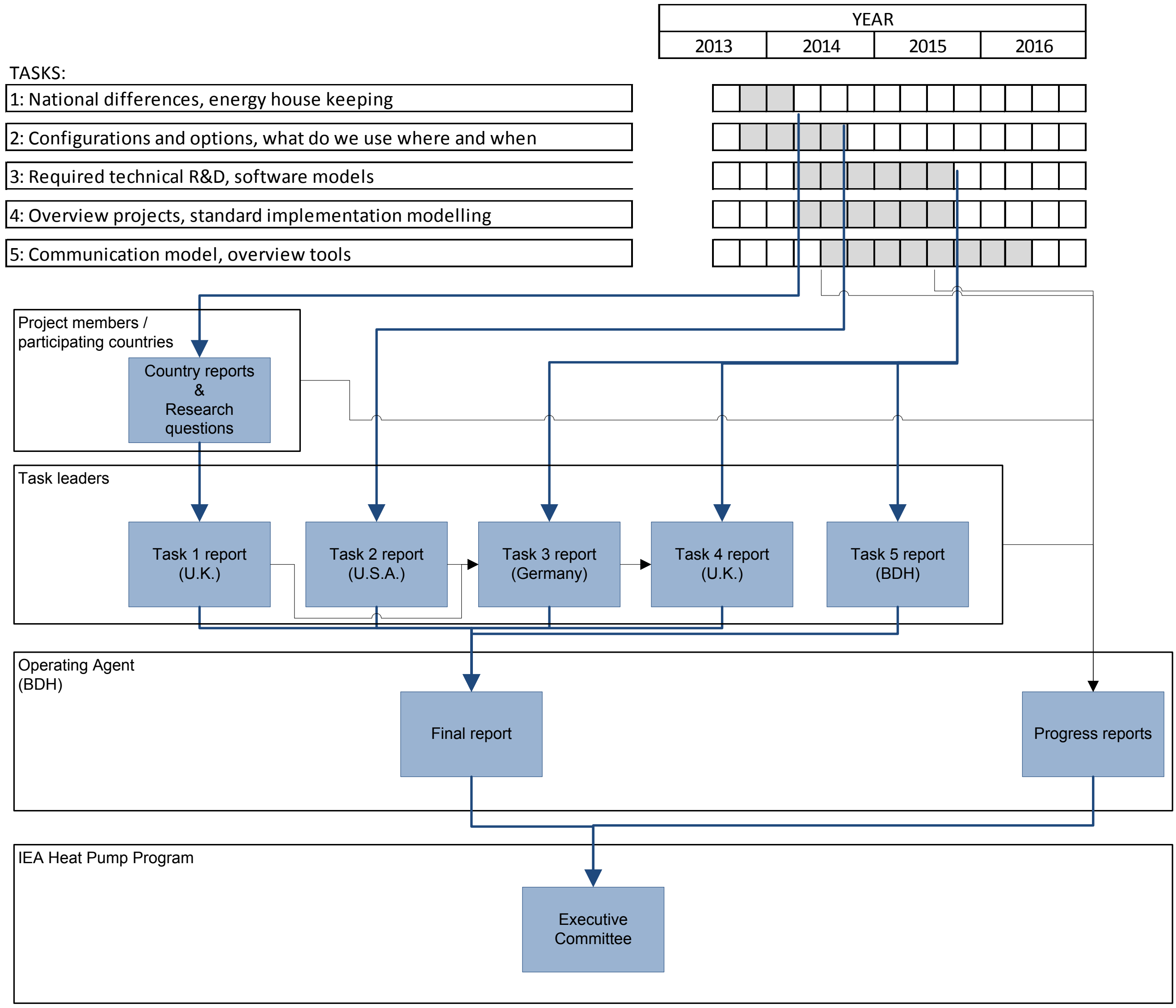
Started in Summer 2013, Annex 42 is running at full speed, with the following participants:

1. United Kingdom
   (Department of Energy and Climate Change, DEltaEe);
2. The Netherlands
   (RVO, DHPA, B E & S, Alliander, TNO Innovatie);
3. South Korea
   (Korean Institute for Energy Research (KIER);
4. USA
   (Oak Ridge Loaboratory, Energy Perf. Research Institute (EPRI));
5. Switzerland
   (Hochschule from Luzern);
6. Denmark
   (Danish Technology Institute (DTI);
7. France
   (Electricité de France (EDF);
8. Germany
   (Fraunhofer ISE);
9. Austria
   (Austrian Institute for Technology (AIT) and University of Graz).
10. Sweden
    (SP and KTH) is in the process of arranging the procedure to become a full participant in Q1-2015.

The work of Annex 42 is based on a project breakdown as shown in Table 1.

Flexibility and storage are essential elements for successful implementation of heat pumps in smart grids, and consequently were main topics for activities between the meetings in 2014, and also discussed during the Annex 42 project meeting in January 2015 in Utrecht – The Netherlands. An indicator, such as what is known as a ‘flexibility index’ - a number to rate the grade of flexibility of a dwelling - is recognized as of potential interest to investigate further, but needs more thorough investigation. Each country identified four case

Table 1: Annex 42 Project break down



scenarios consisting of a typical heat pump application combined with a specific housing type.
With the case scenarios now defined, simulations will be made of the flexibility and storage potential they offer in a smart grid context. Aggregated projections will then be available for estimating the true potential of heat pumps in smart grids in domestic housing in the ten countries in this annex.
Due to the variety of energy systems, building stock, heating habits and energy cost, a wide variety of case scenarios is identified in the various countries. This variety will offer a wealth of insights and knowledge in the second half of this project, from January 2015 until September 2016.
A visualization of the necessity of smart grids technology for heat pumps by means of developing flexibility and suitable storage options is shown in the graphs below, which show a typical urban area power consumption on a coldest winter day, when heat pumps run at full load, in 2013 and 2030.

Figure 1 shows a typical 24-hour load profile for the electricity grid in an urban area in 2013, with negligible loads from heat pumps.

Figure 2 shows already significant increases in grid load caused by a modest penetration of heat pumps in the same area. This emphasizes the necessity of smart girds, by means of flexibility and storage, and at the same time the huge potential for handling electricity from renewable, intermittent, production by means of heat pumps.

Task # 1, Country report has been finalized.
Tasks # 2 and 3 are on track.
Tasks # 4 and 5 will start in the course of 2015, as parallel-run activities.

The next Annex 42 meetings will be in June 2015, at the Department of Energy and Climate Change (DECC) in London, UK, and in November 2015 at the Korean Institute for Energy Research, South Korea.

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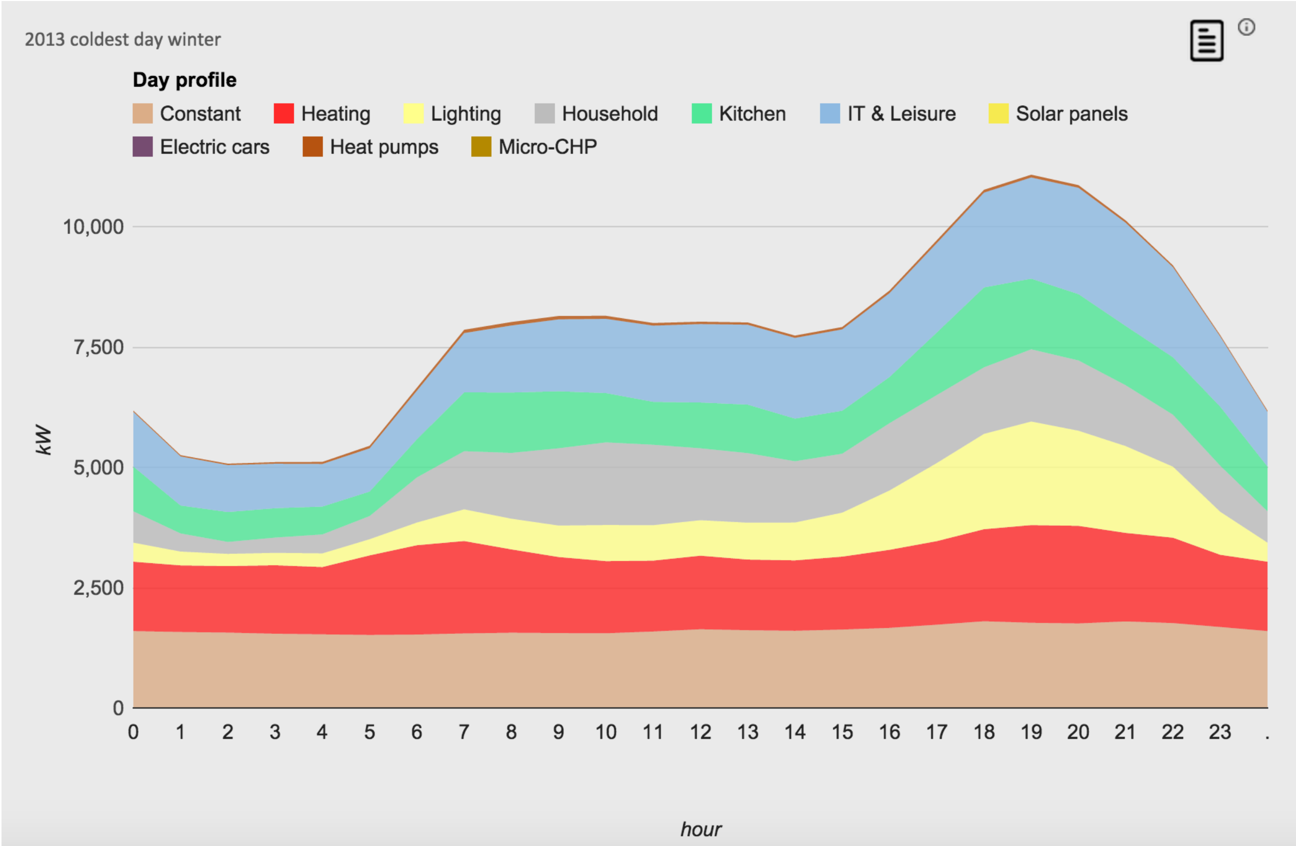
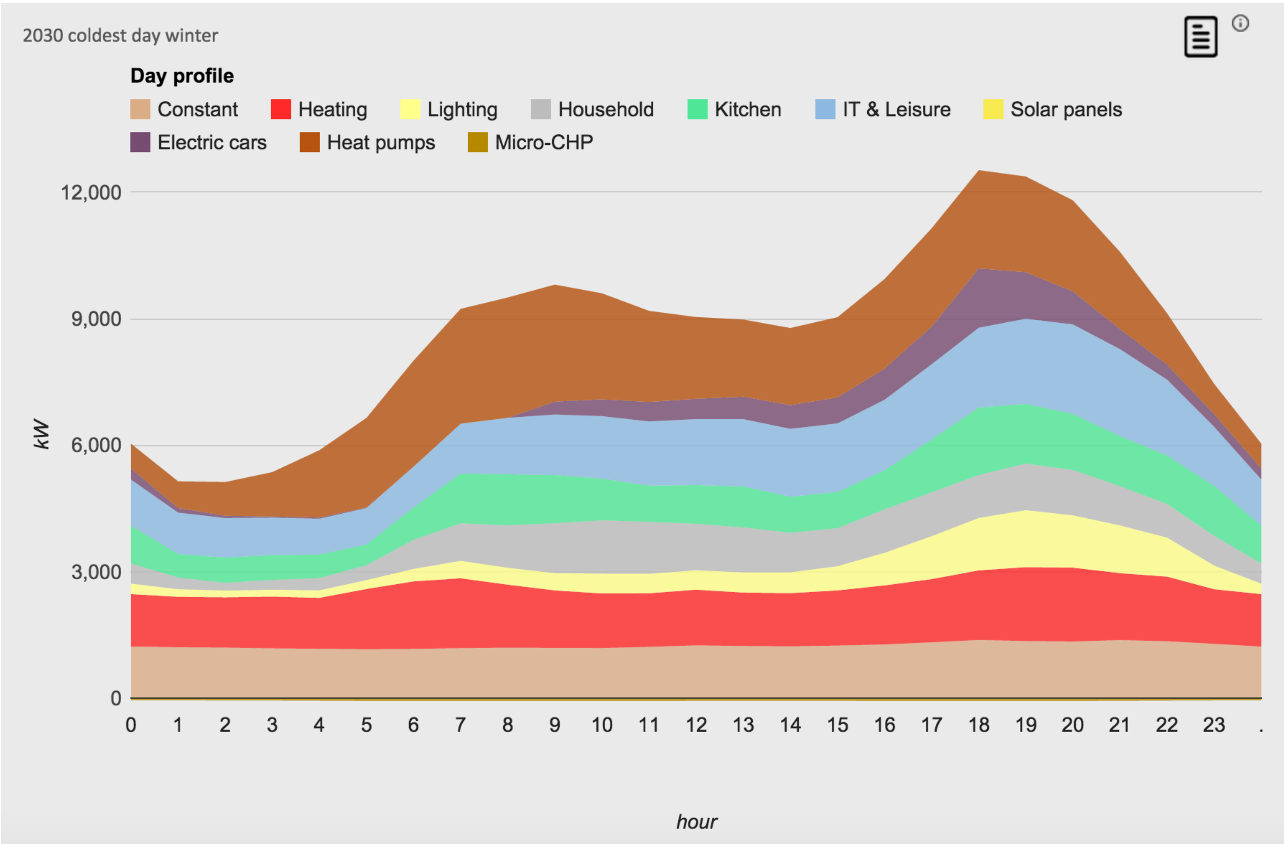


Annex 42: Figure 1. Coldest day in winter 2013 [Source: BDH, Scenario tool domestic energy consumption]



Annex 42: Figure 2. Coldest day winter 2030 [Source: BDH, Scenario tool domestic energy consumption]

IEA HPP Annex 43 Fuel-driven sorption heat pumps

During the period while work was in progress on Annex 34 "Thermally Driven Heat Pumps for Heating and Cooling", there was a growing interest in the area of fuel-driven sorption heat pumps, with more and more products approaching market release. A new Annex, "Fuel-driven sorption heat pumps", was therefore proposed to the ExCo in March 2012. After an Annex definition meeting, a legal text was compiled and accepted as a draft by the ExCo. The new annex, Annex 43, started officially in July 2013, with a planned duration of four years. So far, seven countries have confirmed joining the annex (AT, DE, FR, IT, KR, UK, US); some more have expressed their interest (Poland, China), but of course more participants are welcome.

Objectives

The scope of the work under this Annex will be the usage of fuel driven sorption heat pumps in domestic and small commercial or industrial buildings or applications. If applicable, the additional possibility of supplying cold will also be considered. The main goal is to widen the use of fuel-driven heat pumps by accelerating technical development and market readiness of the technology, as well as to identify market barriers and supporting measures.

HPP Annex 43

Annex 43: Annex structure

Annex 43: Field test of a new prototype of an absorption heat pump.

The Annex structure

The tasks are further specified as follows.

Task A: Generic Systems and System Classification

- Available sources and heating systems
- Existing market and regulatory boundary conditions

Task B: Technology Transfer

- Link research to industrial development for faster market penetration of new technologies
- Novel materials (e.g. MOFs for adsorption heat pumps)
- Novel components (integrated evaporators/condensers, compact heat exchangers)
- System designs (e.g. façade collector as heat source)

Task C: Field test and performance evaluation

- Measurement/monitoring procedure standardisation (e.g. how to cope with different fuel quality, system boundaries, auxiliary energy, etc.)

- Extend standards to seasonal performance factors at the system level

Task D: Market potential study and technology roadmap
- Simulation study to evaluate different technologies in different climate zones, different building types and building standards
- Combine with market data and actual building stock for technology roadmap

Task E: Policy measures and recommendations, information
- Dissemination
- Workshops for planners, installers and decision makers
- Develop recommendations for policies, e.g. building codes and funding schemes

Within Task A, a template for the country report was prepared by ISE and sent out to the participants, it will be completed in spring 2015.

A presentation on the Annex was given at the Heat Pump Summit 2013 in October 2013 in Nuremberg, Germany, and at several more local events.
This summer Korea joined the Annex as the seventh country.

The third meeting was held on November 6-7 in Freiburg with about 24 participants from 8 countries (including observers from the Netherlands and Russia). One of the major outcomes of this meeting was the common interest to start a large field test (> 1000 systems) on fuel driven sorption heat pumps to prove the efficiency of this technology, gather more information of ideal system layouts, and increase awareness. This idea will be discussed with interested parties from gas industry and heating manufacturers. If there is enough interest, possibilities for additional public funding will be evaluated.

More information about the annex can be found at:
https://www.annex43.org/

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IEA HPP Annex 44 Performance indicators for energy efficient supermarket buildings

Annex 44, “Performance Indicators for Energy Efficient supermarket Buildings”, has now reached the halfway mark, with 1.5 years of the total 3 years completed. The ongoing talks for possible new participation with Denmark and the USA will be completed. A further search for additional participants will not be directed at this Annex, but at a possible follow-up.

The data that was collected in The Netherlands from 150 supermarkets of a single supermarket chain is still being analysed, and shows an unexpected trend regarding the opening hours performance indicator. Whereas it is quite natural to assume that electricity consumption will increase with the shop opening hours, the actual data does not show this trend. Therefore additional data that was collected earlier will be added to the analysis to further elaborate on this performance indicator. Also, new data collected by the Swedish team will be used for this purpose, as well as for the general analysis of performance indicators..

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IEA HPP Annex 45 Hybrid Heat Pumps

Heat pumps and fossil fired boilers as hybrid heat pump systems

For space heating and domestic hot water systems in residential and light commercial buildings

Introduction

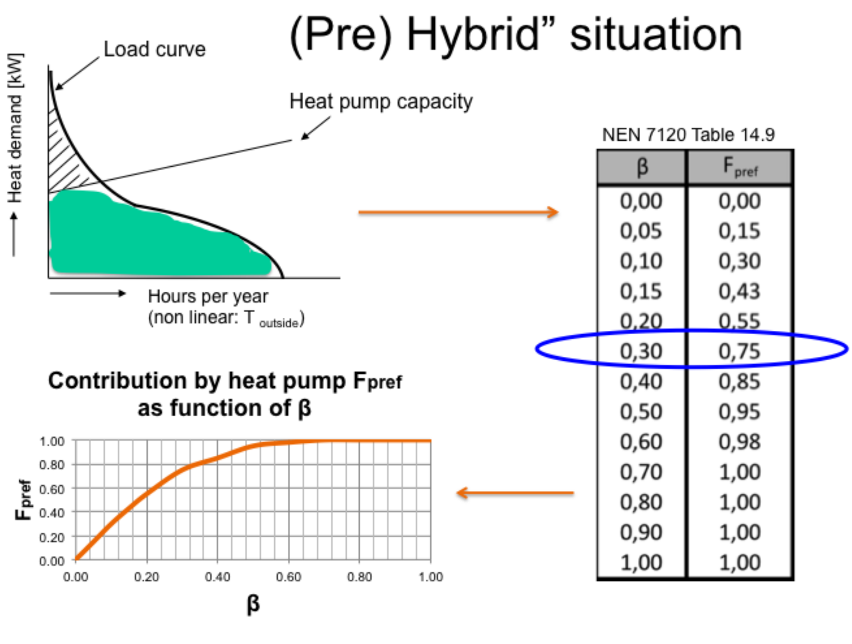
Retrofit and boiler replacement markets are the most important markets for heating and domestic hot water (DHW) production in the residential sector in Europe at this moment. The average technical lifespan of heating devices is 15-20 years. In many cases, no changes to the heat distribution system are made, although higher supply temperatures (> 50 °C) are frequently needed.

Insulation retrofitting during the building lifespan allows a decrease in the heating supply temperature, which makes such buildings interesting for efficient implementation of heat pump technology for a substantial part of the heating season. This also offers a chance for more rapid CO_2 emission reduction, not least by ‘hybridizing’ existing running installations by adding a heat pump to an existing boiler, which can help open up a phenomenal undisclosed opportunity for far greater use of renewable energy.

Objectives

The main objective is to investigate the potential of energy and emission of greenhouse gases emission reduction by greater use of hybrid heat pumps, both through replacement of boilers and by means of upgrading system efficiency in existing running installations.

Figures 1 and 2 show one of the essential elements in hybrid heat pump technology, switching and controlling strategies for the combined heat genearating devices.



β	F_{pref}
0,00	0,00
0,05	0,15
0,10	0,30
0,15	0,43
0,20	0,55
0,30	0,75
0,40	0,85
0,50	0,95
0,60	0,98
0,70	1,00
0,80	1,00
0,90	1,00
1,00	1,00

Figure 1. Pre hybrid situation

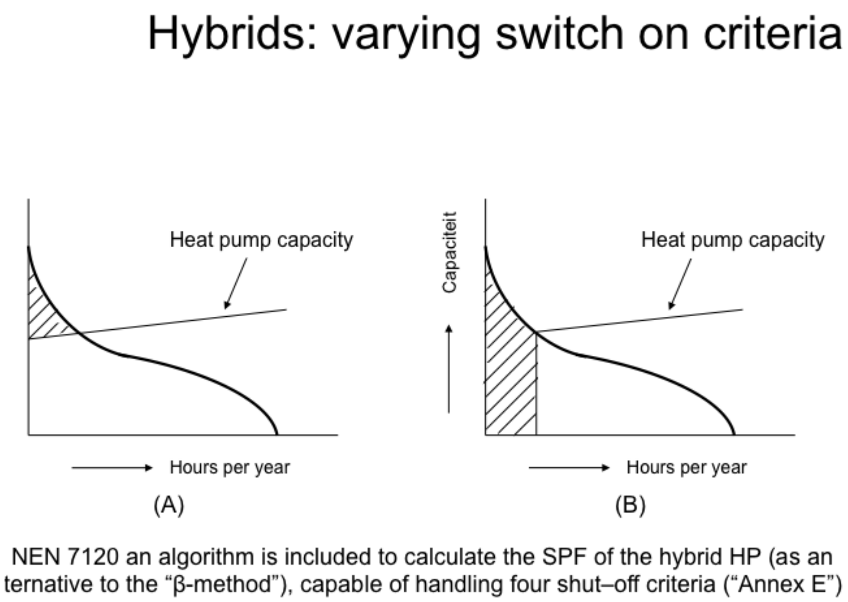


Figure 2. Switching criteria in hybrids

Context of the Annex 45

The focus of this Annex will be on the residential sector, as well as the light commercial sector, where the market overview shows potential. The annex participants foresee justification to investigate this specific segment.

The objectives will be achieved by the participants in the following structure.

Task 1:
Market overview and system classification:

Country Reports: Market structure, market players, products, available systems and configurations, legislation, energy supply scenarios etc.; Product (system) analysis and classification.

Task 2:
Performance evaluation and quality assessment:

- Assessment and further development of laboratory test methods at system level
- Package solutions or which type of system configuration
- Comparison of testing experience among the participants according to the common test protocol as defined in Task 2
- Technology comparison with other heat pump configurations on the market
- Recommendations for quality assurance measures

Task 3:
Modelling and simulation of components and systems:

- Collection of existing and development of new models (validated, where possible)
- Definition of standardised boundary conditions, to be determined in parallel with Task 2
- Simulation of various systems in a wide range of operating conditions (climates, applications, energy scenarios etc.)
- Sensitivity analysis and application matrix

Task 4:
Standardized field test procedures and evaluation:

- Development of a standardised monitoring/field test procedure
- Agree on a common definition for system boundaries and performance evaluation figures
- Collection and analysis of measurement data
- Definition of best practice

Task 5:
Knowledge dissemination and market support:

- Provide information on the results to a broad audience spectrum
- Web site and dedicated Wikipedia page
- Workshops for target groups such as installers and planners
- Final report.

Target audience

The target audiences of this annex are the manufacturers of hybrid heat pumps, engineers, planners, housing corporations, installers, (governmental) policy-makers, research scientists, normative bodies.

Deliverables

Deliverables task # 1:

- Market overview from the collated country reports
- Classification of the hybrid systems per climate zone, per country

Deliverables task # 2:

- Report on testing procedure and testing experience
- Recommendations for quality assurance measures

Deliverables task # 3:

- Improved component and system models
- Standardised boundary conditions
- Report on system performance under different operating conditions, with different system configurations and control strategies (application matrix)

Deliverables task # 4:

- Definition of standards for field testing of hybrid systems
- Best practice for application of hybrid heat pumps

Deliverables task # 5:

- Web site
- Material from the workshops
- Final report

Time Schedule

The Annex will commence in Spring/Summer 2015 and run until Summer 2018.

Potentially interested participants in this annex

Organization	Country
Electricité de France (EDF)	France
Rijksdienst voor Ondernemend Nederland (RVO)	The Netherlands
Fraunhofer ISE	Germany
Austrian Institute for Technology (AIT)	Austria
Korean Institute for Energy Research (KIER)	South-Korea
Department of Energy Saving and Climate Change (DECC)	UK
Politecnico di Milano	Italy

Operating agent

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IEA HPP Annex 46 Heat Pumps for Domestic Hot Water

Abstract

The IEA Executive Committee on Heat Pumping Technologies has agreed on the start of an annex on domestic hot water heat pumps. This paper describes the challenges for domestic hot water heat pumps in a fast growing market and the potential for improvement of equipment and systems which is the focus of the new annex.

Introduction

Heat pumps can be used to heat water very efficiently, and major CO_2 and energy reductions can be realized by employing heat pump technology for water heating.

Domestic hot water heat pumps (DHW HPs) are heat pumps designed for the production of hot water only, traditionally used for bath/shower and kitchen. These types of heat pumps have been a growth engine for the European heat pump market over the last two years, growing to the tune of 30 % per year against a trend of slight decline in the wider heat pump market. A doubling of the market size for DHW HPs is foreseen by 2017, particularly driven by the electric water heater replacement market and oil boiler upgrade market. This is not only the case for Europe; but is also visible as a market trend in the US, Japan and China, with great potential in Canada [1]. In combination with solar-PV, DHW HPs are overtaking and phasing out the market for solar thermal systems in Germany. However, for low energy housing, solar thermal systems can be successfully combined with DHW HPs.

France will continue to be the biggest market in Europe, with a growth rate in 2014 of 50 %, but opportunities are growing in several other markets, including Germany, Sweden, Poland, Benelux, Italy and

Spain – if the right products and customer offers emerge. The greatest potential for domestic hot water heat pumps is in applications for:

- New low-energy buildings and nZEB's where the energy requirement for domestic hot water is overtaking the energy requirement for space heating, and split heat generators are an important option
- Replacement of direct electrical or oil fired heating of domestic hot water in existing buildings
- Replacement of collective domestic hot water systems in apartment blocks and multi-family buildings by individual domestic hot water generators.
- Smart-grid applications, where the storage capacity of the domestic hot water tank provides added value.

A high performing and efficient generator is the key when choosing the right DHW system. However, the overall system efficiency depends on more than the efficiency of the generator alone. While the end user may only be interested in the efficiency of the apparatus, energy policy is concerned with the complete chain from primary (fossil) energy to the end user, and overall efficiencies have to be compared. The benefits of a highly efficient production device can be nullified by poor system integration and high storage or distribution losses [2]. This is a crucial point in the development of an energy-neutral society within a smart energy infrastructure.

New technologies have been reaching the market in the last decade, such as the CO_2 heat pump water heater in Japan, the booster heat pump in Europe [3] and the ability, with new compressor technologies, to generate high temperatures. The combination with DHW in one combi heat pump is a state of the art application in the domestic space heating and cooling market in Europe [4].

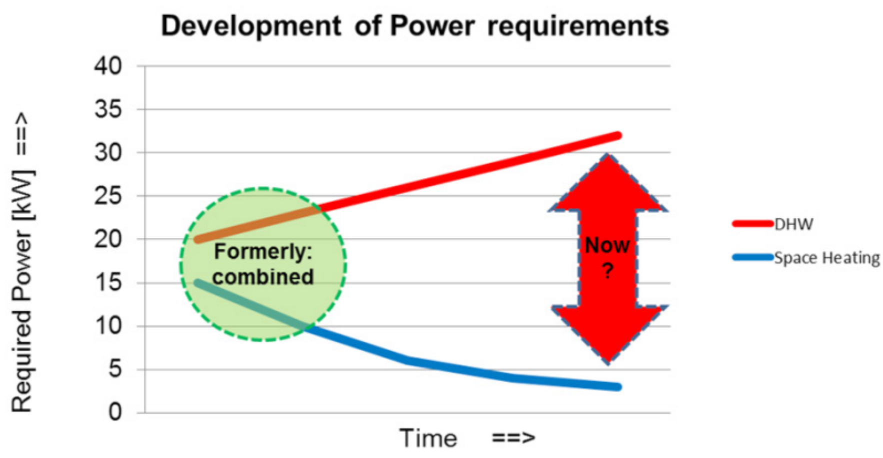

Figure 1. Trends in direct capacity demands of DHW and space heating [2]

Due to a strict governmental policy on energy performance for new residential buildings, inherently better insulation and higher comfort demands for domestic hot water (DHW) by the end user, DHW presents the highest demand for energy use in the house.

Although the overall potential is less than for existing buildings, the concepts need an integral approach to optimize the overall system.
New buildings and designs that fit into smart grids, where the storage capacity of the domestic hot water tank gives added value, is a new market. For existing buildings, this is another challenge. Annex 42 'Heat Pumps in Smart Grids' reported that in some of the participating countries there is a limited physical space for storage (to enable flexibility). Storage tanks for domestic water are not a tradition due to the excellent gas grid and particular in the UK, Korea and the Netherlands, where homes are amongst the smallest by area in Europe. Although hybrid heat pumps, powered from smart grids, can provide the necessary flexibility [5], they are not end users' first choice, due to the ability of gas boilers to supply instantaneous domestic hot water, despite the quite low performance of the gas boiler [2].

Work in Annex 46

The main focus of the annex will be on arranging the information on DHW heat pumping technologies for the market, ranging from end user to consultant, building contractor and policy-maker in such a way that it will lead to better understanding of the opportunities and using them in the right way in order to reduce the use of primary energy, CO_2 emissions and energy costs.

The objectives will be achieved by common studies performed by the participants for each country, where the work under Annex 46 includes:

- Reviewing available domestic hot water heat pumps, including their non-technical (future) issues, and analysing and reporting on the differences
- Reviewing the different system concepts for domestic hot water in their various applications, including recent innovations and application potential
- Gaining a better understanding of the use of domestic hot water in order to create a solid basis for test and standardisation procedures.
- Developing and validating a model to enable an objective comparison of domestic hot water heat pumping technologies and systems

- Data base construction with showcases to inform stakeholders of the viability of concepts, and setting up and monitoring demonstration projects or field experiments
- Creating a web-based information platform to serve participating countries by publishing information on their market approach and training courses. The dissemination and communication activities will be based on the annex's findings and will also be shared with the adjacent annexes.
- Holding regular workshops
- An overview of R&D on DHW HPs, along with the R&D still needed, will be provided to industry players, institutes and governments with the aim of achieving simple and low-cost solutions with an installer- and end-user-focused design based upon a system-wide perspective.

Better awareness of the actual performances of systems is needed in the analyses of the systems, as the results can be very system-dependent. In the first place, it can be assumed that the overall use of DHW influences the performance of the system. At present, there is no real-time information on the actual consumption of hot water, with the exception of some measurements in the UK [6]. Measurements in the Netherlands, taken from over 250 houses of the same design and same household size, along with the same DHW HP, show a difference in the energy use of hot water by a factor of 4! An important focus of the annex will thus be to obtain an insight into the following and other factors: Draw-off curves and volumes, Length of in-house piping from generator to tap; Standstill losses from the storage tank; Draw-off efficiencies and stratification in the storage tank; Control strategy of stored DHW; Temperature of stored DHW. With this information, models can be constructed to assist the choice of robust and reliable systems for the coming decades, for which it is important that all the factors are taken into account.

A new model, thus developed, has to be aligned with the existing test procedures for DHW HPs. However, a harmonization process must be initiated in this field of expertise. An ISO report [7] noticed the need for the harmonization of standards. In June 2013, TC86/SC6 of the International Standards Organization (ISO) agreed in principle to develop a new test standard for heat pump water heaters. However, this will take some time to develop, given the need to address different climate zones, levels of hot water use and draw-off patterns. Furthermore, there is no guarantee that an ISO test, whenever finalized, would be adopted in all the countries that have pre-existing test standards, so the problem of multiple test standards may persist for some time. It is not withing the remit of this annex to start a process of harmonization, but the findings under Tasks 2 and 3 will be used as input to the development of standards by the ISO TC 86 SC 6 working group, which is undertaking this work in 2015.

Although DHW HPs seem to be readily available on the market, development as well as research are still needed to increase the performance of the heat pump itself as well as the DHW side of the DHW HP and the storage system. The US Department of Energy has studied this thoroughly and has developed a road map [8], in which the main goals are:

- Simple and low-cost solutions
- Installer- and end-user-focused designs
- System-wide perspective that reflects understanding of the water/energy nexus

After characterising and analysing each initiative, DOE presents a table which shows both direct-impact initiatives, which address specific technical innovations to provide energy savings, as well as enable initiatives, which indirectly aid improvements in energy efficiency via supplementary technologies, processes, or knowledge advances.

Relation to other HPP annexes

The objective of Annex 46 is to analyse the information on DHW heat pumping technologies and structure it for the market - ranging from end user to consultant, building contractor, and policy-maker - in such a way that leads to better understanding the opportunities and implementing them in order to reduce the use of primary energy, CO_2 emisions and energy costs.

Other currently running annexes and newly proposed Annexes are partially working in the same field and covering some of the same topics. These annexes under the HPP are:

- Annex 40 – Heat Pumps in Nearly Zero Energy Buildings, where DHW is the main energy demand for heating and where technology has to be developed to fit into the smart grid.
- Annex 42 – Heat Pumps in Smart Grids, has to deal with all types of buildings where DHW HPs can have a storage function, and hybrid heat pumps can be part of the solution
- Annex 45 – Hybrid Heat Pumps in Europe mainly have gas boilers for DHW, but can have a heat pump and storage tank for DHW
- Annex 47 - Heat Pumps in District Heating can cover part of the challenge for thermal smart grids and can cover part of the question for NZEBs. But special DHW HPs can also be part of the low-temperature distribution challenge.
- Proposed Annex on Multi-Family Buildings, where finding a solution for DHW can be one of the challenges and where hybrid heat pumps can be one of the solutions.

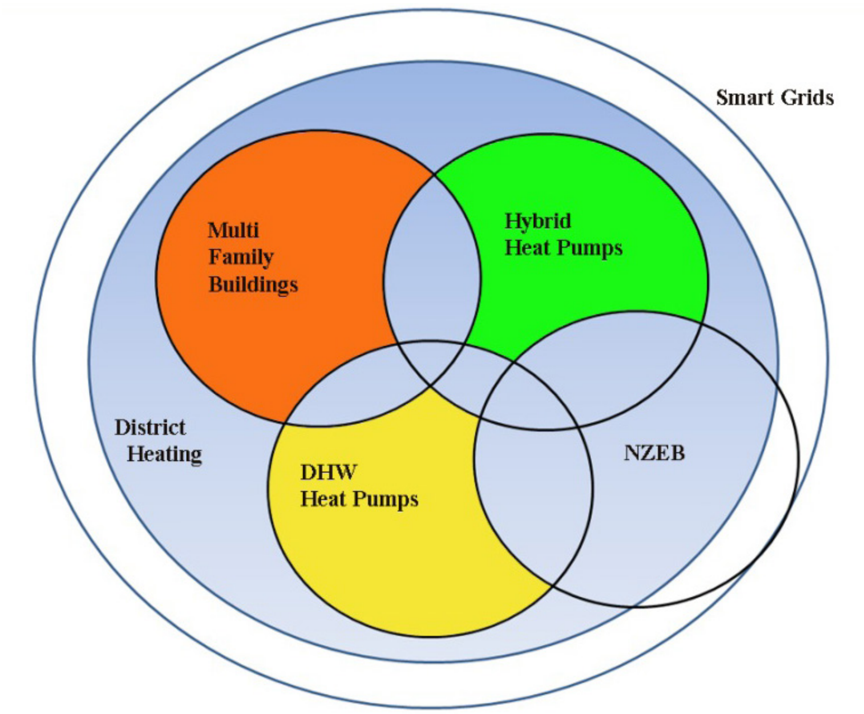

Figure 2. Overlap in annexes

The foreseen overlap in the Annexes can be pictured as Figure 2.

Conclusions

The main deliverables of this annex are:

a. An Internet website (linked to the Implementing Agreements sites), giving up-to-date information on: market overview with possible applications and examples of demonstration projects or cases; tools for the sizing of Domestic Hot Water heat pumps and calculating their energy and economic performances; good practice guide, evaluating users' experience in different projects.

b. Insight in real performances and use of domestic hot water as input for standards and calculation models

c. An online database about available technologies, components, materials for, and R&D on DHW heat pumps.

d. A reference guide describing presently available domestic hot water heat pump systems with their applications; software tools, their application and users' experience.

e. Usable input for the development of training courses for installers in the various participating countries

This annex is in its development stage, and is seeking more participants than the present four countries. It will start its work officially by August 2015. Before that, a working meeting will be announced through the Heat Pump Centre and to the delegates for the Executive Committee.

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Ongoing Annexes

Bold text indicates Operating Agent.

Annex 36 Quality Installation/Quality Maintenance Sensitivity Studies	36	FR, SE, UK, **US**
Annex 37 Demonstration of Field measurements of Heat Pump Systems in Buildings – Good examples with modern technology	37	CH, NO, **SE**, UK
Annex 39 A common method for testing and rating of residential HP and AC annual/seasonal performance	39	AT, CH, DE, FI, FR, JP, KR, NL, **SE**, US
Annex 40 Heat Pump Concepts for Nearly Zero-Energy Buildings	40	CA, **CH**, DE, FI, JP, NL, NO, SE, US
Annex 41 Cold Climate Heat Pumps (Improving Low Ambient Temperature Performance of Air-Source Heat Pumps)	41	AT, CA, JP, **US**
Annex 42 Heat Pump in Smart Grids	42	CH, DK, FR, KR, **NL**, UK, US
Annex 43 Fuel Driven Sorption Heat Pumps	43	AT, **DE**, FR, IT, UK, US
Annex 44 Performance Indicators for Energy Efficient Supermarket Buildings	44	**NL**, SE
Annex 45 Hybrid Heat Pumps	45	**NL**
Annex 46 Heat Pumps for Domestic Hot Water	46	**NL**

IEA Heat Pump Programme participating countries: Austria (AT), Canada (CA), Denmark (DK), Finland (FI), France (FR), Germany (DE), Italy (IT), Japan (JP), the Netherlands (NL), Norway (NO), South Korea (KR), Sweden (SE), Switzerland (CH), the United Kingdom (UK), and the United States (US).
All countries are members of the IEA Heat Pump Centre (HPC). Sweden is the host country for the Heat Pump Centre.

Improved reliability of Swedish residential heat pump systems

Caroline Haglund Stignor, Sweden

This article describes a study of the most common failures of residential heat pumps in Sweden, aiming at suggesting measures to be taken to reduce the number of failures. Methods used were analysis of public failure statistics and interviews with installers, service technicians, manufacturers, sales agents and claims adjusters at insurance companies. It was concluded that failures are probably often caused by poor installation, neglected maintenance and surveillance, and/or poor quality of standard components or use of components outside their declared operating range, and that different types of measures must be taken to improve the reliability further.

Introduction

Today, heat pump heating systems are common in Swedish single-family houses for space heating and domestic hot water production. Most owners are pleased with their installation, but statistics show that a certain number of heat pumps break down every year, resulting in high costs for both insurance companies and owners (Folksam, 2012).

On behalf of Länsförsäkringsbolagens Forskningsfond, SP Technical Research Institute of Sweden has studied the causes of the most common failures for residential heat pumps in Sweden (Haglund et. al, 2012). The objective of the study was to suggest what measures could be taken to reduce the number of failures, i.e. further improving the reliability of heat pumps. The target group of the study was mainly insurance companies and owners of heat pumps.

The heat pump market is mature in Sweden. During the last ten years, half of Swedish house owners have bought a heat pump (SVEP, 2011). Figure 1 shows the number of heat pumps sold in Sweden over the last 30 years. The columns represent air to air (purple), closed brine system (green), exhaust air (red) and air to water (blue) heat pumps. Figures for

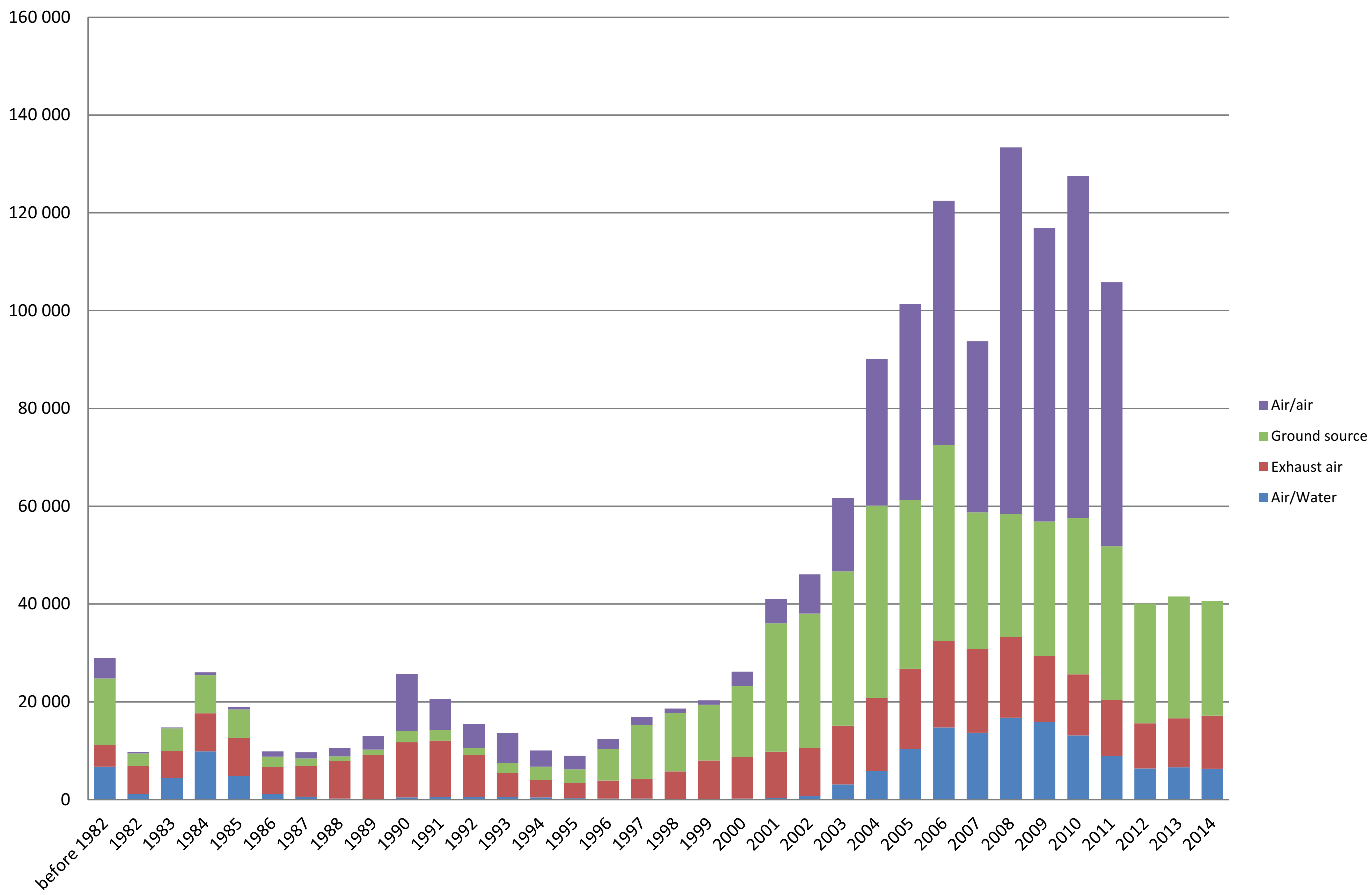

Figure 1. Number of heat pumps sold between 1982 and 2014 in Sweden [Source: SVEP, 2014]

air to air heat pumps are approximations, since not all heat pumps that are sold are reported to SVEP, and have not been included at all for the last two years (due to high uncertainty).

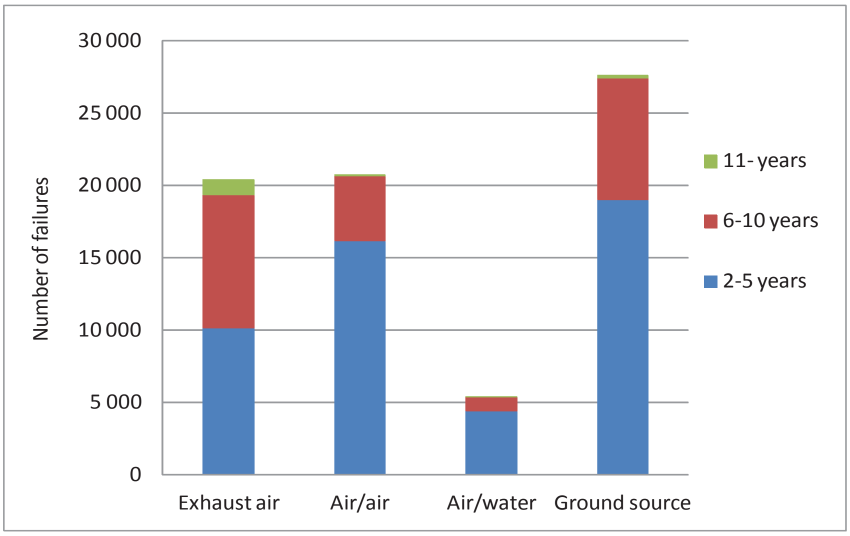

Figure 2. Age of heat pumps at failure reported to Swedish insurance companies, between 1999 and 2010

Method

The scope of the study was to analyse why heat pumps in single-family houses fail in operation or break down, and what could be done to prevent the failures.

The methods used were:

1. Analysis of failure statistics to identify the most common types of failures

2. Interviews with heat pump installers, service technicians, manufacturers, sales agents and claims adjusters at the insurance company Länsförsäkringar.

Failure statistics

Swedish heat pump failure statistics were analysed and used as a basis for the questions in the interviews. Public statistics for failures reported to the Swedish insurance company Folksam were used to identify common failures of air-to-air, air-to-water, exhaust air and ground-source heat pump types (Folksam, 2012). Annual statistics of failures were available for the years 2006 to 2010,

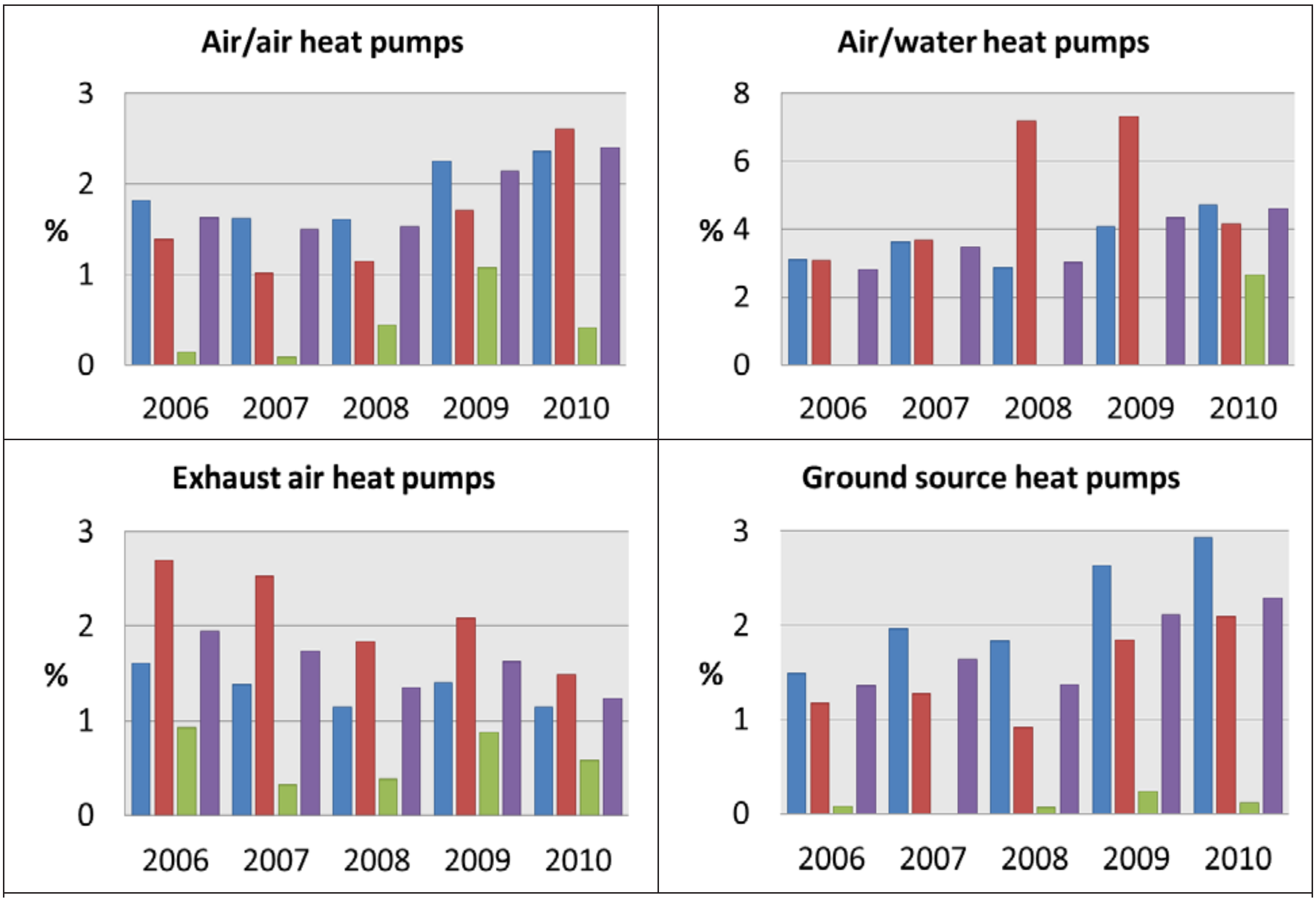

Figure 3. Number of failures in relation to the number of installed heat pumps of a certain age, blue: 2-5 years, red: 6-10 years, green: 11-12 years, purple: mean value for all ages

and the figures were assumed to be representative for all failures reported to Swedish insurance companies. The statistics were used to see both numbers of failures and trends of the failures. The statistics included heat pumps that were two years old or older, since failures that arise during the first two years after installation are covered by warranty. Figure 2 shows the age of the different heat pump types when failures were reported to the insurance companies. The diagram shows that most of the heat pumps were two to five years old when a failure was reported. One reason why quite recently installed heat pumps are so common in the statistics is that the possible amount of payment from insurance companies decreases yearly. One can assume that failures for some of the older heat pumps were corrected without involvement of insurance companies.

The failure statistics were thereafter compared to the sales statistics in order to be able to evaluate the number of failures in relation to the number of sold units, see Figure 3. It can be seen that for air/air heat pumps there is an increasing trend for the number of failures in relation to all installed units, and that for air/water heat pumps peaks can be seen for 2008 and 2009 for units of an age of 6-10 years. For exhaust air heat pumps the trend is decreasing, while it is increasing for ground source heat pumps, although still at relatively low form of levels, since on average about 2 % of all installed heat pumps of that type reported some failure.

Interviews with Stakeholders in the Heat pump industry

The interviews were aimed at examining different stakeholders' opinions regarding reasons for heat pump failures and what can be done to prevent the failures. Installers, service technicians, manufacturers, sales agents and claims adjusters were interviewed. The interviews were used to categorise the common failures into four groups;

- Could the failure have been prevented by better operation and maintenance of the heat pump?
- Was the failure caused by poor quality of installation work?
- Could the failure have been prevented if certain parameters had been measured, recorded and followed up?
- Was the failure due to poor quality of components or systems?

The aim of the categorisation was to enable suggestion of measures to reduce the number of heat pump failures. The interviews also included general questions about installation and service procedures, manuals, maintenance and the owners' interests and knowledge of their heat pump installations.

The study was based on a total of 38 interviews. The basis for the selection of interviewees was to cover different regions in Sweden, since the mean outdoor temperature varies between about +2 °C in the north and +10 °C in the south of the country. In addition, the amount of snowfall and the distance from the sea differs between regions, and these factors may affect the heat pump components. All larger heat pump brands in Sweden were represented among the installers and service technicians. Even though the number of interviews was limited, the study indicates the reason why a certain number of heat pumps fail in operation.

Interviews with Installers and service technicians

This section describes the interviews with heat pump installers and service technicians, who work with heat pumps in the owners' homes. The questions to these two groups were similar. Eleven interviews were conducted with installers and the number of service technicians who were interviewed was sixteen, all representing different companies.

What did the installers say?

Most of the installers

- find the manuals good enough, but some do not use them.
- think that they receive adequate instructions from the manufacturers
- fill in the installation protocol if provided (not all), however, it is seldom required or asked for

Half of the installers

- think that there is not much problem with residential heat pumps in detached houses / apartment buildings
- recommend regular service.

Installers who also perform service and repairs consider accessibility when placing the outdoor unit. Often little space is available. Owners want the outdoor unit to be as invisible as possible. The placement of the indoor unit also controls the placement of the outdoor unit.

What did the service technicians say?

- Most owners are satisfied with their heat pump
- The failures arising are caused by
  - Lack of knowledge of some installers
  - Lack of maintenance
  - Poor quality of certain components
  - Import of heat pumps not suitable for the Swedish climate
- Only certified refrigeration technicians or certified installers should be allowed to install heat pumps
- Installation protocols are not always completed and seldom requested
- Troubleshooting and repairs could be faster and cheaper if performed by technicians with higher competence
- Experience a decreasing trend of compressor failures

- Experience a decreasing trend of problems with the directional control valves
- Regular service could reduce the wear of the compressor
- They get good support from manufacturers when troubleshooting

Manufacturers and sales agents

Four heat pump manufacturers, as well as sales agents and SVEP (The Swedish Heat Pump Association) were interviewed.

What did they say?

- Four of seven manufacturers and selling agents, contacted by us, took part in the interview study
- Their confidence in insurance companies was not the best
- Most of them recall components during, but not after, the warranty period
- Some manufacturers do not impose special requirements for installers, but offer training, some sell only through trained and approved installers
- Manufacturers recommend regular service
- Manufacturers often require the service technicians to check certain things for the warranty to apply. The insurance companies could do the same
- SVEP believes that the number of failures of heat pumps could be reduced if installers and service technicians were better trained, and offers such training.

Claims adjusters

Seven claims adjusters were interviewed, all working for the Länsförsäkringar insurance company in Sweden. Both city regions and countryside regions were represented. All the interviewed claims adjusters noted that there are many failures of heat pumps, but could not say whether the failure rate has increased or not.

What did they say?

- Some manufacturers offer supplementary insurance after the warranty period – this can cause problems
- None of the interviewed claims adjusters
  - » asks for installation protocols
  - » makes random checks to verify that replaced components really are faulty or broken
- None of them requires regular service of heat pumps for compensation to be paid, but many of them think it could be a good idea
- Some feel that heat pumps with well-kept "service records" should be rewarded
- Heat pump owners need more and better information about the need to take care of their heat pump

Measures to prevent failures

Monitoring of parameters

From the interviews it was concluded that some compressor failures could be prevented if any of the following parameters were monitored:

- COP
- temperature differences of fluid
- pressure drop across filters
- temperature after the directional control valves
- numbers of start / stop
- number of defrosts

It could also be concluded that to prevent the heat pump from breaking down, the time that the heat pump works with high pressure differences, i.e. large temperature rises, should be minimized.

Cooperation between actors in Heat pump chain

In addition, it was concluded from the project that better cooperation between actors in the heat pump chain is needed. Some repairs become unnecessarily expensive because of insufficient competence. Higher skills and troubleshooting diagrams are therefore needed. Insurance companies could use the same service technicians or have similar requirements as some manufacturers have for paying compensation during the warranty period. There is a need for more certified refrigeration technicians. Actors in the heat pump chain should inform young people about the job opportunities that can be offered. On top of that, prospective heat pump owners should be encouraged to choose a certified installer and a quality-labelled product. Regular service or function performance checking could reduce the number of failures, and heat pump owners need to be informed about this!

Information for homeowners

The number of failures could probably be decreased by more and better information to the homeowners, such as:

- When purchasing, ask for quality, not just for performance!
- Examine what applies for service and warranty
- Hire a certified installer / refrigeration technician
- If the installation is carried out in summer, ask for a revisit in the winter
- Be present during part of the installation to get information about maintenance

Homeowners should also be told how to perform general supervision themselves (or hire a professional), such as:

- Check if the heat pump is working in its correct operating mode
- Check the temperature sensors
- Check, clean / replace filters
- Listen for noise changes
- Make sure there are no air bubbles in the sight glass (if visible)

- Clean the house's ventilation extraction points (exhaust)
- Exercise the directional control valve (if there is a DHW tank)
- Check that the heating system is bled correctly and at the right pressure level
- Keep the outdoor unit free of snow and ice (air/air and air/water)
- Remove the front panel and check for leaks, etc. (if there is a DHW tank)

Insurance companies could provide this information to their costumer if they want do reduce the number of failures!

Conclusions

Statistics show that a certain number of heat pumps fail every year. However, the installer and service technicians who were interviewed were generally of the opinion that the owners were pleased with their heat pumps, and that the number of heat pumps with problems is small in comparison with the total number of such systems installed in Swedish single-family houses.

The interviewees stated that heat pump failures are often caused by:

- poor installation
- neglected maintenance and surveillance
- poor quality of standard components
- the use of components outside their declared operating range

The following is required if the operational reliability of the residential heat pumps is to be improved:

- Information for owners, installers, service technicians
- Incentives for owners, manufacturers, installers and service technicians to make "the right choice"
- Communication and cooperation between the different parties in the heat pump sector

The insurance companies can contribute to all points above, which was very valuable information for them to obtain.

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Impact of Installation Faults on Heat Pump Performance

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Numerous studies and surveys indicate that typically-installed HVAC equipment operate inefficiently and waste considerable energy due to varied installation errors (faults) such as improper refrigerant charge, incorrect airflow, oversized equipment, and leaky ducts. This article summarizes the results of a large United States (U.S.) experimental/analytical study (U.S. contribution to IEA HPP Annex 36) of the impact that different faults have on the performance of an air-source, single-speed heat pump (ASHP) in a typical U.S. single-family house. It combines building effects, equipment effects, and climate effects in an evaluation of the faults' impact on seasonal energy consumption through simulations of the house/ASHP pump system.

Introduction

The U.S. technical contribution to Annex 36 (Domanski et al., 2014) explores the impact that typical installation faults have on the performance of a single-speed, 8.8 kW (2.5-ton), ducted, split-system ASHP installed in a single-family house; rated seasonal cooling and heating performance factors (SPFc and SPFh) of 3.81 W/W and 2.26 W/W (U.S. SEER and HSPF of 13 Btu/Wh and 7.7 Btu/Wh), respectively. The laboratory/modeling project combined building, equipment, and climate effects in a comprehensive evaluation of the impact of installation faults on annual energy consumption of the ASHP via seasonal simulations of the house/heat pump system. Faults were evaluated both individually and in combination. The fault parameters evaluated in the study are listed in Table 1. The fault parameters were based on the requirements found in the ANSI/ACCA 5 QI – 2010 Standard "HVAC Quality Installation Specification" (ACCA, 2010), along with two additional faults: excessive liquid line refrigerant subcooling and undersized field-installed thermal expansion valve (TXV). The annual energy consumption analyses were conducted for two different house types (one with a slab foundation and a second with basement foundation) in five locations representative of the range of U.S. climate condition.

Table 1. Studied faults, definitions, and fault ranges [Source: Domanski et al, 2014]

Fault name	Symbol	Definition of fault level	Fault levels (%)
Improper indoor airflow rate	AF	% above or below correct airflow rate	CM: -36, -15, +7, +28 HM: -36, -15, +7, +28
Refrigerant undercharge	UC	% mass below correct (no-fault) charge	CM: -10, -20, -30 HM: -10, -20, -30
Refrigerant overcharge	OC	% mass above correct (no-fault) charge	CM: +10, +20, +30 HM: +10, +20, +30
Excessive liquid line refrigerant subcooling (indication of improper refrigerant charge)	SC	% above the no-fault subcooling value	CM: +100, +200 HM: none
Presence of non-condensable gases	NC	% of pressure in evacuated indoor section and line set, due to non-condensable gas, with respect to atmospheric pressure	CM: +10, +20 HM: +10, +20
Improper electric line voltage	VOL	% above or below 208 V	CM: -8, +8, +25 HM: -8, +8, +25
TXV undersizing	TXV	% below the nominal cooling capacity	CM: -60, -40, -20 HM: none
Duct leakage	DUCT	% of total equipment airflow that leaks out of the duct distribution system (60% supply leakage, 40% return leakage).	CM: +0, +10, +20, +30, +40, +50 HM: +0, +10, +20, +30, +40, +50
Heat pump sizing	SIZ	% above or below optimum heat pump capacity	CM: -20, +25, +50, +75, +100 HM: -20, +25, +50, +75, +100
			Notes: CM = Cooling Mode HM = Heating Mode

Laboratory Analysis

The undertaken laboratory analyses resulted in correlations that characterize the ASHP performance with no faults (baseline case) and with the first seven faults listed in Table 1. The last two faults in Table 1 were modeled only. Figures 1 and 2 illustrate the indoor and outdoor sections, respectively, of the ASHP as installed in the environmental test chambers at the U.S. National Institute of Standards and Technology (NIST). Figure 3 illustrates the measured impact of indoor air flow faults on the test heat pump COP. Full details and results of the lab tests may be found in Domanski et al. (2014).

Figure 1. ASHP test unit in chamber – indoor section

Figure 2. ASHP test unit in chamber – outdoor section

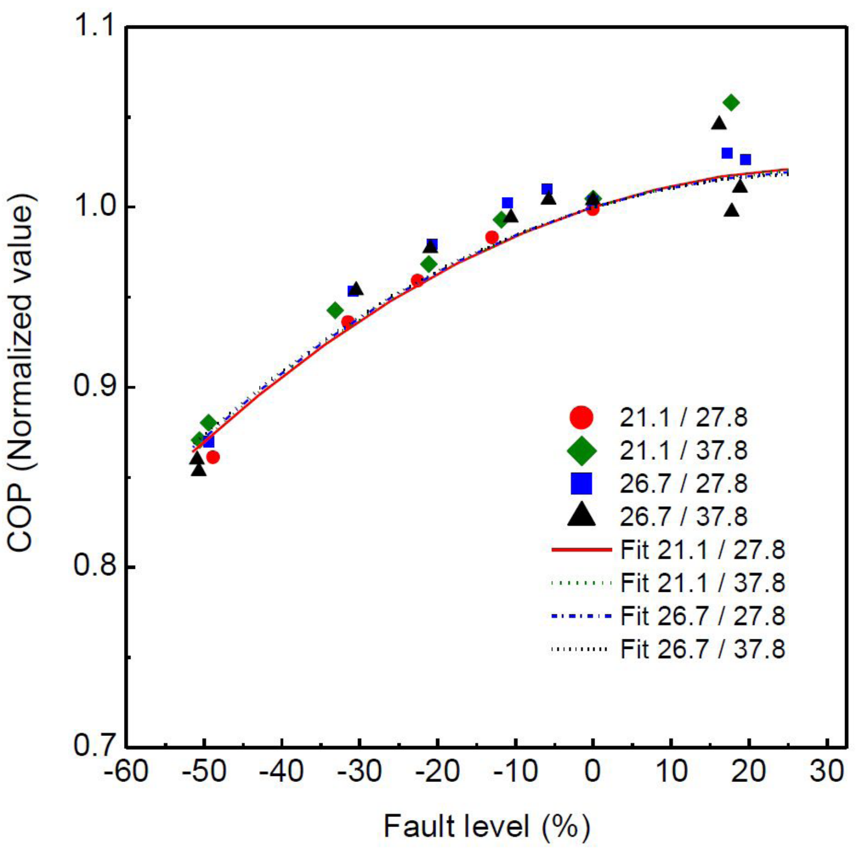

Figure 3. ASHP measured cooling COP vs. faults in indoor airflow (from -50 % to +20 % of the design flow; the legend denotes indoor dry-bulb / outdoor dry-bulb temperatures, °C)

Simulations of Building / ASHP Systems with Installation Faults

These simulations, using the laboratory-determined performance correlations, estimated the annual energy consumption (combined heating and cooling) of the subject ASHP for both normal (baseline or no fault) operation and for various intensities of the studied installation faults. The simulations focused strictly on system performance issues; no effort was made to quantify impacts on occupant comfort, indoor air quality, noise generation (e.g., airflow noise from air moving through restricted ducts), equipment reliability/robustness (number of starts/stops, etc.), maintainability (e.g., access issues), or costs of initial installation and ongoing maintenance.

A building model developed in TRNSYS was used to simulate the integrated performance of the subject ASHP/house systems in this study (CDH Energy Corp., 2010). The model is driven by typical meteorological year weather data sets TMY3 (Wilcox and Marion, 2008) on a small time-step (e.g., 1.2 minutes).

A detailed thermostat model turns the heat pump "on" and "off" at the end of each time step, depending on the calculated space conditions. Table 2 lists the climates with representative locations and house structures considered in this study. The selected cities represent U.S. climate zones 2 through 6 as shown in Figure 4. This selection enabled prediction of how different faults will affect ASHP performance in the most prevalent climates in the U.S.

Two 190 m² (2,000 ft²) three-bedroom houses were modeled: a slab-on-grade house, and a house with a basement. A 2-zone model was employed for the slab-on-grade foundation house – living space and attic zones. A 3-zone model was developed for the basement foundation house – living space, attic, and basement zones. The basement was not directly conditioned, but coupled to the main living space via zone-to-zone air exchange. These buildings corresponded to code-compliant houses with appropriate levels of insulation and other features corresponding to each climate (Domanski et al., 2014). The slab-on-grade houses were modeled with air distribution ducts located in the attic. The houses with basements were modeled with ducts located in the semi-conditioned basement space. For Houston, TX, only a slab-on-grade house was studied because houses with basements are rarely built in this location.

Table 2. Climates, locations and structures considered [Source: Domanski et al., 2014]

Zone	Climate	Location	Slab-on-grade house	House with basement
2	Hot and humid	Houston, TX	Yes	No
3	Hot and dry climate	Las Vegas, NV	Yes	Yes
4	Mixed climate	Washington, DC	Yes	Yes
5	Heating dominated	Chicago, IL	Yes	Yes
6	Cold	Minneapolis, MN	Yes	Yes

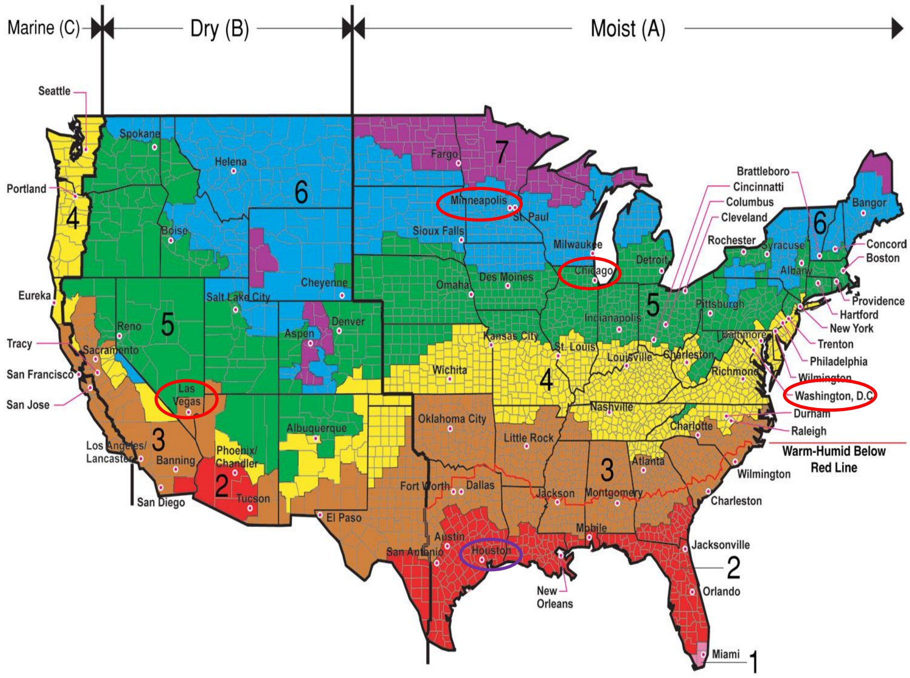

Figure 4. U.S. climate zones with locations for simulation indicated

Impact of Single Installation Faults on Heat Pump Performance

Table 3 shows representative impacts of the studied faults on ASHP annual energy use (relative to "no fault" energy use). It is anticipated that the selected levels of individual faults reflect an installation condition which might not be noticed by a poorly-trained or inattentive technician.

In most cases, the effect of installation faults is similar for both house types. Duct leakage faults (DUCT) in the slab-on-grade house can cause the highest increase in energy use among the faults studied, especially in the colder locations. It is expected that duct leakage will also result in some increase of energy use for the basement house; however, the modeling approach employed could not discern this increase.

The next most influential faults were refrigerant undercharge (UC), refrigerant overcharge (OC), and improper airflow across the indoor coil (AF). For the 30 % undercharge fault (UC) level, the energy use increase is on the order of 20 %, regardless of the climate and building type. Refrigerant overcharge (OC) can also result in a significant increase in energy use, 10 - 16 % at the 30 % overcharge fault level. Improper indoor airflow (AF) can affect similar performance degradation. [Note: Excessive refrigerant subcooling (SC) correlates to refrigerant overcharge (OC); 100 % subcooling is approximately equivalent to 20 % refrigerant overcharge.] An oversized heat pump (SIZ) coupled with undersized air ducts can cause >10 % energy use increases in the hot climate locations. The undersized cooling TXV fault (TXV) also has the potential to significantly increase the energy use in the hot locations.

Table 3. Annual energy use impacts for an ASHP due to each individual studied installation fault vs. a fault-free installation [Derived from: Domanski et al., 2014)]

Fault type	Fault level	Relative energy use (%) [100 is baseline]								
		Slab-on-grade house installation (Air ducts located in unconditioned attic)					Basement house installation (Air ducts in conditioned basement)			
	%	HOU	LV	WAS	CHI	MIN	LV	WAS	CHI	MIN
AF	- 36	112	113	114	113	111	111	112	112	110
UC	- 30	121	122	123	120	117	120	121	119	117
OC	+ 30	110	110	114	113	112	111	116	115	113
SC	+ 200	118	116	119	118	116	118	120	120	119
NC	+ 10	102	102	101	101	101	102	101	101	101
VOL	+ 8	102	101	102	102	101	101	102	102	102
TXV	- 40	114	110	107	105	107	109	105	103	102
DUCT	+ 30	118	117	124	126	126	100*	100*	100*	100*
SIZ#	+ 50	115	113	105	101	99	114	108	104	102

U.S. cities included in the study: **HOU** → Houston, TX **LV** → Las Vegas, NV **WAS** → Washington, DC **CHI** → Chicago, IL **MIN** → Minneapolis, MN
* duct leakage into basements assumed to have no energy impact
\# coupled with undersized air ducts

Table 4. Combinations of studied faults [Source: Domanski et al., 2014]

Fault combination case	Level of fault A	Level of fault B
A	Moderate	Moderate
B	Moderate	Vorst
C	Worst	Moderate
D	Worst	Worst

Table 5. Impact of combined refrigerant undercharge and air duct leakage faults on ASHP energy use in three U.S. locations

Air duct leakage + low refrigerant charge (Houston)		20% Duct leakage	40% Duct leakage
		109%	128%
15% Undercharge	105%	**115%**	**136%**
30% Undercharge	121%	**132%**	**156%**
Air duct leakage + low refrigerant charge (Washington, DC)		**20% Duct leakage**	**40% Duct leakage**
		112%	139%
15% Undercharge	105%	**117%**	**146%**
30% Undercharge	123%	**137%**	**172%**
Air duct leakage + low refrigerant charge (Minneapolis)		**20% Duct leakage**	**40% Duct leakage**
		113%	140%
15% Undercharge	103%	**116%**	**144%**
30% Undercharge	117%	**132%**	**162%**

Impact of Dual Installation Faults on Heat Pump Performance

The combination of two faults, A and B, were considered in the following four combinations as listed in Table 4 above.

The 'moderate level' is the value at the middle of the range, while the 'worst level' is the highest (or lowest) probable level of the fault value (see Table 1). In the full study (Domanski et al., 2014), simulations of 14 fault combinations were conducted: duct leakage coupled with system oversizing, restricted air flow, refrigerant overcharge or undercharge, or noncondensible gases; system oversizing coupled with refrigerant undercharge or overcharge, or noncondensible gases; restricted air flow coupled with refrigerant undercharge or overcharge, or noncondensible gases; and undersized TXV coupled with duct leakage, system oversizing, or restricted airflow. The results indicated that the impact of combinations of two faults on annual energy use may be additive (A+B), less than additive (<A+B), or greater than additive (>A+B). Figure 5 illustrates simulation results for the combination of duct leakage and refrigerant undercharge for Houston, Washington, and Minneapolis (spanning the range of U.S. climate conditions from hot to very cold). For the lower refrigerant undercharge fault, the combined impact is approximately additive in all locations. At the greater undercharge fault level, the combined impact is slightly amplified.

Selected Findings

Extensive simulations of house/heat pump systems in five U.S. climatic zones lead to the following conclusions:

- Duct leakage, refrigerant undercharge, oversized heat pump with undersized ductwork, low indoor airflow due to undersized ductwork, and refrigerant overcharge have the most potential for causing significant performance degradation and increased annual energy consumption.
- The effect of different installation faults on annual energy

use is similar for a slab-on-grade house and a basement house, except for the duct leakage fault.

- The effect of two simultaneous faults can be additive (e.g., duct leakage and non-condensable gases), little changed relative to the single fault condition (e.g., low indoor airflow and refrigerant undercharge), or beyond additive (e.g., duct leakage and refrigerant undercharge).
- The laboratory and modeling results from this fault analysis on an 8.8 kW (2.5 ton) heat pump are considered to be representative of all unitary equipment, including commercial split-systems and single package units.

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Events

2015

10 – 14 March
ISH
Frankfurt, Germany
http://ish.messefrankfurt.com/frankfurt/en/aussteller/willkommen.html

16 – 17 March
ATMOsphere Europe 2015
Brussels, Belgium
http://www.ATMO.org/europe2015

16 – 18 April
6th IIR Ammonia and CO_2 Refrigeration Conference
Ohrid, Republic of Macedonia
http://www.r744.com/events/view/615

19 – 24 April
World Geothermal Congress
Melbourne, Australia
http://wgc2015.com.au/index.php

6 – 9 May
Advanced HVAC and Natural Gas Technologies 2015
Riga, Latvia
http://www.hvacriga2015.eu/

19 – 21 May
13th IEA Energy Conservation through Energy Storage (ECES) Greenstock Conference 2015
Beijing, China
http://greenstock2015.csp.escience.cn/dct/page/1

26 – 28 May
The 6th International Conference on Heating, Ventilating and Air Conditioning
Tehran, Iran
http://hvacrnews.ir/files/ichvac6_brochure.pdf

28 May
8th EHPA European Heat Pump Forum
Brussels, Belgium
http://forum.ehpa.org/

1 – 6 June
eceee 2015 Summer Study on energy efficiency
Toulon/Hyères, France
http://www.eceee.org/summerstudy

25 – 26 June
ATMOsphere America 2015
Atlanta, USA
http://www.atmo.org/events.details.php?eventid=30

27 June – 1 July
ASHRAE Annual Conference
Atlanta, USA
https://www.ashrae.org/membership--conferences/conferences

16 – 22 August
ICR 2015 – The 24th IIR International Congress of Refrigeration
Yokohama, Japan
http://www.icr2015.org/

30 September – 2 October
ASHRAE Energy Modeling Conference
Atlanta, USA
https://www.ashrae.org

20 – 21 October
Heat Pump Summit
Nuremberg, Germany
http://www.hp-summit.de/en/

20 – 23 October
8th International Conference on Cold Climate-Heating, Ventilation and Air-Conditioning (Cold Climate HVAC 2015)
Dalian, China
http://www.coldclimate2015.org/

2016

23 – 27 January
ASHRAE Winter Conference
Orlando, USA
https://www.ashrae.org/membership--conferences/conferences/ashrae-conferences

7 – 9 April
4th IIR Conference on Sustainability and the Cold Chain
Auckland, New Zealand
http://www.iifiir.org/medias/medias.aspx?INSTANCE=exploitation&PORTAL_ID=general_portal.xml&SETLANGUAGE=EN

22 – 25 May
12th REHVA World Congress - CLIMA2016
Aalborg, Denmark
http://www.clima2016.org

25 – 29 June
ASHRAE Annual Conference
St. Louis, USA
https://www.ashrae.org

21 – 24 August
Gustav Lorentzen Natural Working Fluids Conference
Edinburgh, Scotland
http://www.ior.org.uk/GL2016

11 – 13 October
Chillventa
Nuremberg, Germany
http://www.chillventa.de/en/

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