Technology Collaboration Programme on Heat Pumping Technologies (HPT)

Annex 56

Digitalization and IoT for Heat Pumps

Final Report

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Preface

This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), which is a Technology Collaboration Programme within the International Energy Agency, IEA.

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of nearly 40 Technology Collaboration Programmes.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the implementing agreement for a programme of research, development, demonstration and promotion of heat pumping technologies. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP, collaborative tasks, or “Annexes”, in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex.
The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

Disclaimer

The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programmes or TCPs. The TCPs are organised under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

The Heat Pump Centre

A central role within the HPT TCP is played by the Heat Pump Centre (HPC).

Consistent with the overall objective of the HPT TCP, the HPC seeks to accelerate the implementation of heat pump technologies and thereby optimise the use of energy resources for the benefit of the environment. This is achieved by offering a worldwide information service to support all those who can play a part in the implementation of heat pumping technology including researchers, engineers, manufacturers, installers, equipment users, and energy policy makers in utilities, government offices and other organisations. Activities of the HPC include the production of a Magazine with an additional newsletter 3 times per year, the HPT TCP webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
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The Annex was operated from 01/2020 to 12/2022. Further information is available on the Annex website https://heatpumpingtechnologies.org/annex56/

Participating countries

The following countries participate in Annex 56:

- Austria
- Denmark
- France
- Germany
- Norway
- Sweden
- Switzerland

A detailed presentation of the national teams and their research work is available on the Annex website https://heatpumpingtechnologies.org/annex56/participants/

Participants and contributors

This final report is the result of a collaborative effort with contributions from various authors that are listed in the table below. The report was edited by Veronika Wilk (AIT), veronika.wilk@ait.ac.at

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Foreword

Today, more and more devices are connected to the Internet and can interact due to increasing digitalization – the Internet of Things (IoT). In the energy transition, digital technologies are intended to enable flexible energy generation and consumption in various sectors, thus leading to greater use of renewable energies. This also applies to heat pumps and their components.

IEA HPT Annex 56 explores the opportunities and challenges of connected heat pumps in household applications and industrial environment. There are a variety of new use cases and services for IoT enabled heat pumps. Data can be used for preventive analytics, such as what-if analysis for operation decisions, predictive maintenance, fine-tuning of the operation parameters and benchmarking. Connected heat pumps allow for demand response to reduce peak load and to optimize electricity consumption, e.g. as a function of the electricity price. Digitalization in industry can range from automated equipment, advanced process control systems to connected supply value chains. IoT enabled heat pumps allow for integration in the process control system and into a high level energy management system, which can be used for overall optimization of the process.

IoT is also associated to different important risks and requirements to connectivity, data analysis, privacy and security for a variety of stakeholders. Therefore, this Annex has a broad scope looking at different aspects of digitalization and creates a knowledge base on connected heat pumps. The Annex aims to provide information for heat pump manufacturers, component manufacturers, system integrators and other actors involved in IoT.

Abstract

Digitalization is one of the most important factors for the transformation of energy systems, as it is expected to facilitate the matching of supply and demand in the face of increasing volatility of energy production and contribute significantly to final energy savings and CO_2 reductions. Heat pumps are becoming networked devices that can participate in the Internet of Things (IoT). The IEA HPT Annex 56 project analyses the opportunities and challenges of IoT-enabled heat pumps for use in buildings and industrial applications. The project provides a structured overview of IoT-enabled heat pumps and commercial products and services, that was developed in an intensive exchange with experts from Austria, Denmark, France, Germany, Norway, Sweden and Switzerland.

In total, 44 application examples were analyzed that clearly show that IoT-enabled heat pumps and products based on them are already available on the market. Five categories are assigned to the application examples: Heat pump operation optimization, Predictive Maintenance, Heat pump operation commissioning, Provision of flexibility and Heat as a service. Relevant interfaces, data analysis methods and business models for IoT heat pumps were analyzed. The use of IoT technology and connectivity can enable or significantly improve data exchange, analysis and the services based on it. For the users, this enables operating cost and energy savings and increased operational reliability. For the energy system, the provision of flexibility is of particular importance, as it allows for better integration of fluctuating generation of renewable energy. The exchange and use of data play an essential role.

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1. Executive Summary

Ambitious climate, energy and environmental goals require the transition to an efficient, renewable, and low-carbon energy system. Digitalization is one of the most important factors for the transformation of energy systems, as it is expected to facilitate the matching of supply and demand in the face of increasing volatility of energy production and contribute significantly to final energy savings and CO_2 reductions. According to an IEA study, digitalization can reduce energy consumption in buildings by 10% by 2040. Heat pumps are increasingly becoming networked devices that can participate in the Internet of Things (IoT). Such heat pumps, both domestic and industrial, enable optimization of operation to reduce energy consumption, lower CO_2 emissions, achieve economic benefits and increase comfort. They also enable grid services through the targeted provision of flexibility, e.g., in a pool of small heat pumps or with large heat pumps for industrial or district heating applications.

The IEA HPT Annex 56 project analyses the opportunities and challenges of IoT-enabled heat pumps for use in buildings and industrial applications. The aim of the project is to provide a structured overview of IoT-enabled heat pumps and commercial products and services. The presented data and information were developed in an intensive exchange with experts from the participating countries (Austria, Denmark, France, Germany, Norway, Sweden, Switzerland).

The work is structured in five tasks: Task 1 summarizes the state of the art and gives an overview on the industrial Internet of Things, communication technologies and knowledge engineering in automation. It reviews the status of currently available IoT enabled heat pumps, heat pump components and related services in the participating countries and provides information on information security and data protection. A Zotero literature collection with more than 100 items was created. Market overview, a manufacturer survey and experts interviews on IoT and heat pumps were conducted in four countries (Denmark, France, Austria and Sweden). In total, 44 factsheets of IoT use cases and projects were created, thereof 23 from Denmark and 10 from Austria. The examples were compactly summarized in two-page factsheets, that contain information on the description of the technology used (hardware, platform, protocols), explanation of the application (background and benefits, lessons learned) and an info box (Data requirements, analysis methods, modeling requirements, maturity level, etc.).

The examples were then used to describe generalized IoT categories. These five categories summarize similar applications and were explored in more detail in Tasks 2, 3, and 4 to describe and compare aspects related to interfaces, data analysis, and business models in a structured manner. The method of starting with concrete examples proved to be successful because it focuses the analysis on heat pump specific issues and excludes adjacent topics such as higher-level control in the energy system.

Task 2 focuses on the communication infrastructure and identifies requirements for data acquisition from new built and already implemented heat pump systems and provides information on types of signals, protocols and platforms for different heat pump use cases in buildings and industrial applications. Four use cases are discussed in detail based on 10 different examples.

Task 3 gives an overview on data analysis based on examples of IoT products and services. Different targets for data analysis are derived from 32 examples, data analysis methods are categorized and assessed, ranging from visualization and manual analysis to machine-learning algorithms. 16 examples are described in detail, they are mainly research projects. Furthermore, this task provides insights in the pretreatment of data, the use of data models, meta data and BIM (building information modeling).

Task 4 evaluates market opportunities created by connected heat pumps and presents different types of IoT services and business models based on literature and market research including detailed SWOT analyses (strengths, weaknesses, opportunities, and threats). 19 examples of implemented business models are presented.

Task 5 aims at reporting results and disseminating information developed in the Annex. Interactions and synergies with six other Annexes and Tasks in the IEA Technology Collaboration Programs that are also working on digitalization were sought.

Highlights of the project were the Deep Dive Sessions, which took place in the context of the international expert meetings. In these sessions, different aspects of IoT enabled heat pumps are covered based on presentations of research projects presented by the participating organizations and invited external experts. The Deep Dives enable a deeper exchange on concrete questions and thus contribute significantly to the networking of the international participants and to the exchange of knowledge. Ten different Deep Dives were organized.

The results of Annex 56 are published on the website: https://heatpumpingtechnologies.org/annex56/ There, an introduction of the participants, all task reports, the final report providing a structured overview on the work and the factsheets are available. Furthermore, a webinar was carried out to promote the results and the slide deck and the recording of the webinar are provided on the website. Annex 56 yielded numerous publications: 8 presentations at conferences and workshops, 3 conference papers, 6 journal papers (thereof 3 submitted) and 1 magazine publication.

The results of Annex 56 provide a good overview of the risks and opportunities for connected heat pumps. 44 application examples were collected in the participating countries, which clearly show that IoT-enabled heat pumps and products based on them are already available on the market. Five general categories can be assigned to the application examples: Heat pump operation optimization, Predictive Maintenance, Heat pump operation commissioning, Provision of flexibility and Heat as a service. For the user, this typically means operating cost and energy savings and increased operational reliability. For the energy system, the provision of flexibility is of particular importance, as it enables better use to be made of fluctuating renewable energy generation. Exchange and use of data plays an essential role in this.

Various interfaces and protocols for communication are available for networked heat pumps. Often, the connection to the Internet is wireless via WiFi and gateways that connect to the cloud, where data analysis services can be accessed. For heat pumps integrated into building automation, BACnet and Modbus are widely used. In the Austrian survey, Modbus and KNX Fieldbus, UPC UA and BACnet were frequently mentioned. The analysis of the Danish use cases illustrates that different stakeholders need to interact (quickly) at different levels and through different interfaces, for example, API interfaces, Modbus, MQTT, end-user apps, and fog/edge-based computing facilities. The Swedish work shows that interoperability is difficult between heat pumps from different manufacturers and even within a single manufacturer's product range. However, these challenges do not apply exclusively to heat pumps, but more generally to interconnected actors in the energy system. Interoperability and data availability will play an essential role in balancing generation and consumption in the energy system.

Modeling and data analysis are key activities for IoT-enabled heat pump products and services, as they enable meaningful use of collected data to provide targeted information for desired purposes. Five data analysis objectives were collected in the analysis, to which different methods can be assigned: Fault detection, Predictive maintenance, Optimization, Control, and Comparison with other heat pumps. The data analysis methods used in the application examples are visualization and manual analysis, analysis of alarms, KPI calculation and comparison, prediction, MPC (model-based control), MILP (mixed-integer optimization), big data analysis, data model development, and machine learning. The analysis points out that the application largely determines the data analysis method.

IoT-enabled heat pumps are already part of business models and new services. The main benefits for users of IoT-enabled heat pumps are lower costs, more efficient heating systems, and higher reliability. For the heat pump value chain, i.e. component manufacturers, heat pump manufacturers, dealers, installers, digitalization leads to new products and services that make heat pumps more attractive and future-proof. Compared to traditional business models, they have more responsibility for the efficiency of IoT-enabled heat pumps. The energy system (aggregators, suppliers, power grid, etc.) requires flexibility to balance fluctuating renewable generation. Heat pumps can provide flexibility and enable sector coupling by linking the heat and power sectors, which will be particularly relevant for the future. Energy service companies (ESCO) are a new player in the building sector (heat as a service, leasing of heat pumps, heat as a service), they are already established in the industrial sector with heat pump contracting. ESCOs can support the further diffusion of heat pumps, as users in contracting models do not have to deal with the heat pump, but only purchase the heat.

The importance of digitalization for the energy transition has increased further in recent years. Intelligent, digital solutions are increasingly in demand to make efficient use of various flexibility options such as electricity-based heat generation, the use of storage or e-mobility, and to control the power grid securely. Therefore, connected heat pumps will also play an important role in the future energy system. Current efforts of the latest EU action plan to develop a sustainable, cyber-secure and competitive market for digital energy services and digital energy infrastructures underline this. Important fields of action are the definition of common standards and the improvement of the interoperability of devices in the energy system. A common European energy data space for the exchange and use of energy data, as well as a code of conduct for interoperability, are to be created. IoT-enabled heat pumps can contribute to the following EU energy policy objectives: increasing participation in demand response programs for energy-efficient appliances and increasing the cyber security and resilience of the energy system.

2. Introduction

2.1. Background

Ambitious climate, energy and environmental goals require the transformation of the energy system into an efficient and renewable system with low CO_2 emissions. Digitalization is one of the important factors for this transformation. Intelligent, digital solutions are increasingly in demand to efficiently use various flexibility options such as power-based heat generation, the use of storage or e-mobility as well as to safely control the electricity grid. Heat pumps are a versatile technology for the provision of space and process heat, for water heating and for cooling of buildings and processes. According to the IEA's Net Zero by 2050 report, a total of 1800 million heat pumps have to be installed in buildings world-wide to provide more than half of the heating needs. It is a tenfold increase compared with the level of 2020 [2].

As digitalization progresses, heat pumps increasingly become connected devices that participate in the Internet of Things (IoT). They will be equipped with sensors, actuators, network connectivity and software to collect and exchange data. This will make it possible to offer heat pump users the best possible comfort und to further optimize the energy consumption of buildings and processes, and thus make a significant contribution to decarbonizing the heating and cooling supply.

IoT in buildings

According to the JRC report "Digitization: opportunities for heating and cooling", the digitization of heating and cooling will lead to new applications and services, in addition to energy savings and the associated benefits (reduced energy costs, cleaner environment), and thus to increased competitiveness. However, in order for the technologies and business models to become appropriately established on the market, the risks associated with digitalization, such as data protection, cybersecurity, etc., still need to be reduced through new guidelines and laws. [1]

IEA's Net Zero by 2050 report elaborates on the impact of digitalization on emission reduction. Advances in technology, e.g. smart thermostats or other smart appliances lower carbon emissions, as they reduce the necessity for people to play an active role in energy savings. It is expected that emissions from the building sector will be reduced by 350 Mt CO_2 by 2050 due to digitalization and smart controls [2].

IoT in industry

In contrast to the building sector, industrial companies have long been using digital technologies for process control. Industrial IoT (IIoT) platforms and cloud computing are increasingly being used in the manufacturing industry for online monitoring of production plants, cross-site energy management, control and monitoring of decentrally distributed machines and plants, and for centralized recording and evaluation of distributed measuring stations. For industrial applications, energy savings and cost reduction are often linked to productivity increases and optimization of resource use, which are achieved through advanced solutions (supply chain management, condition monitoring, soft sensors, predictive maintenance, etc.). IoT-enabled heat pumps can thus be directly connected to the communication infrastructure of Industry 4.0 networks, making them relevant not only for heating and cooling in buildings, but also for industrial applications and their decarbonization.

IoT in research and development projects

The EU recognized the importance of IoT early on and established the European Research Cluster for the Internet of Things, IERC, in 2007 with the aim of exploiting the great potential of IoT in Europe and coordinating research activities on a horizontal level to generate a critical mass of knowledge, an overview is provided by http://www.internet-of-things-research.eu/. For example, €100 million was made available by the EU in FP7 for IoT R&D projects. According to a report by the Alliance for Internet of Things Innovation (AIOTI), which summarizes IoT applications in 17 EU-funded R&D projects in the field of IoT, one-third of these projects address Smart City, Smart Energy, and Smart Buildings applications, and related devices, such as heat pumps [3]. Thus, numerous hardware and software solutions, platforms, services, and IoT solutions have been developed over the past 8 to 10 years. In addition, the industry has developed and launched its own products and solutions. According to GrowthEnabler, the global IoT market will be worth US$457 billion in 2020. The "Smart Cities" application, which is relevant for heat pumps, has the largest share with 26%, followed by Industrial IoT with 24%; the share of smart buildings is 14%, [4].

Heat pump and component manufacturers have also been offering IoT-enabled products for several years. These include, for example, smart valves and thermostats, integration into a cloud for data analysis and operational optimization, smart home systems with heat pumps, or solutions for controlling and monitoring HVAC systems.

2.2. Scope and objectives of Annex 56

IEA HPT Annex 56 analyzes the opportunities and challenges of IoT-enabled heat pumps for use in buildings and for industrial applications. The aim of the project is to provide a structured overview on IoT-enabled heat pumps that will be disseminated to relevant target groups, such as heat pump and component manufacturers, system integrators and other actors involved in IoT. In addition, the project contributes to the strategic objectives of the IEA Heat Pumping Technologies TCP, which focuses, among other topics, on digitalization and Internet of Things.

Table 1 shows the contents of the five tasks of Annex 56.

Table 1: Structure of Annex 56

Task	Content
Task 1 – State of the Art (Lead: KTH)	This task summarizes the state of the art and gives an overview on the industrial Internet of Things, communication technologies and knowledge engineering in automation. It reviews the status of currently available IoT enabled heat pumps, heat pump components and related services in the participating countries and provides information on information security and data protection.
Task 2 – Interfaces (Lead: AIT)	This task identifies requirements for data acquisition from new built and already implemented heat pump systems and provides information on types of signals, protocols and platforms for different heat pump use cases in buildings and industrial applications.
Task 3 – Data analysis (Lead: Fraunhofer ISE)	This task gives an overview on data analysis based on examples of IoT products and services. Different targets for data analysis are derived, data analysis methods are categorized and assessed, starting with visualization and manual analysis reaching to machine-learning algorithms. The report provides insights in the pretreatment of data, the use of data models, meta data and BIM (building information modeling).
Task 4 – Business Models (Lead: AIT)	This task evaluates market opportunities created by connected heat pumps and presents different types of IoT services and business models based on literature and market research including detailed SWOT analyses (strengths, weaknesses, opportunities, and threats).
Task 5 – Dissemination (Lead: AIT)	This task aims at reporting results and disseminating information developed in the Annex. Interactions and synergies with other Annexes or Tasks in the IEA Technology Collaboration Programs are sought.

2.3. Methodology

The state-of-the-art is based on an extensive literature research, expert interviews, and an online survey. Examples of IoT applications related to heat pumps were collected. Both commercial products and research projects were considered. The examples were compactly summarized in two-page factsheets, which were created using a template for projects and for products. They contain information on

- Description of the technology used (hardware, platform, protocols)
- Explanation of the application (background and benefits, lessons learned)
- Info box: Data requirements, analysis methods, modeling requirements, maturity level, etc.

The examples were collected through research and expert interviews, as well as based on ongoing or completed research projects. The factsheets were prepared together with the companies and research institutions and approved for publication. The examples were then used to describe generalized IoT categories. These five categories summarize similar applications and were explored in more detail in Tasks 2, 3, and 4. Aspects related to interfaces, data analysis, and business models were described and compared using the generalized IoT categories in a structured manner and with concrete examples. The method of starting with concrete examples proved to be successful because it focuses the analysis on heat pump specific issues and excludes adjacent topics such as higher-level control in the energy system.

Highlights of the project were the Deep Dive Sessions, which took place in the context of the international expert meetings. In these sessions, different aspects of IoT enabled heat pumps are covered based on presentations of research projects presented by the participating organizations and invited external experts. The Deep Dives enable a deeper exchange on concrete questions and thus contribute significantly to the networking of the international participants and to the exchange of knowledge:

- Sematic modelling and Building Information Modeling (BIM)
- Data-driven modeling and machine learning
- Hybrid modeling: data-driven models and/or physical models
- Connected heat pumps in industrial applications
- Heat as a service and user interaction
- Hardware in the loop and digital twins
- Safety and security for connected heat pumps
- Digital twins
- Digital operation analysis and digital building twin

3. Results

Table 2 provides an overview on the results elaborated in the different tasks. The task reports and the factsheets are available on the Annex website.

Table 2: Results of the tasks

Task	Results
Task 1 – State of the Art (Lead: KTH)	Task 1 Report: State of the art, literature collection, data security and privacy, application examples from participating countries, experts interviews, manufacturer survey, market review. 44 factsheets for IoT products and services on the Annex website.
Task 2 – Interfaces (Lead: AIT)	Task 2 report: discussion of architecture and interfaces based on concrete examples
Task 3 – Data analysis (Lead: Fraunhofer ISE)	Task 3 report: information on data preparation, data models, metadata and BIM, structuring of methods for data analysis based on 16 examples.
Task 4 – Business Models (Lead: AIT)	Task 4 report: description of already implemented business models for IoT heat pumps, SWOT analysis for selected use cases.
Task 5 – Dissemination (Lead: AIT)	Project website, publications, LinkedIn Posts, networking with other Annex projects Successful implementation of the international project

In the following chapters, the results are presented in a compact way to provide guidance for the different documents.

3.1. Task 1 – State of the Art

3.1.1. State of the Art

The report provides a detailed introduction to the Internet of Things and Industrie 4.0 It gives an overview of communication technologies in automation, describing the different industrial communication protocols and discussing interoperability issues. It also focuses on knowledge engineering, such as information modeling, Building Information Modeling BIM, Automation ML, etc.

In recent years, the Internet of Things (IoT) has fundamentally changed the way technology is used. The concept of connecting devices to the Internet and having them communicate with each other has brought a multitude of opportunities in terms of efficiency, convenience, and automation.

The first mention of the Internet of Things dates to a 2005 report by the International Telecommunications Union (ITU): *“Machine-to-machine communications and person-to-computer communications will be extended to things, from everyday household objects to sensors monitoring the movement of the Golden Gate Bridge or detecting earth tremors. Everything from tyres to toothbrushes will fall within communications range, heralding the dawn of a new era, one in which today’s internet (of data and people) gives way to tomorrow’s Internet of Things.”* [5]

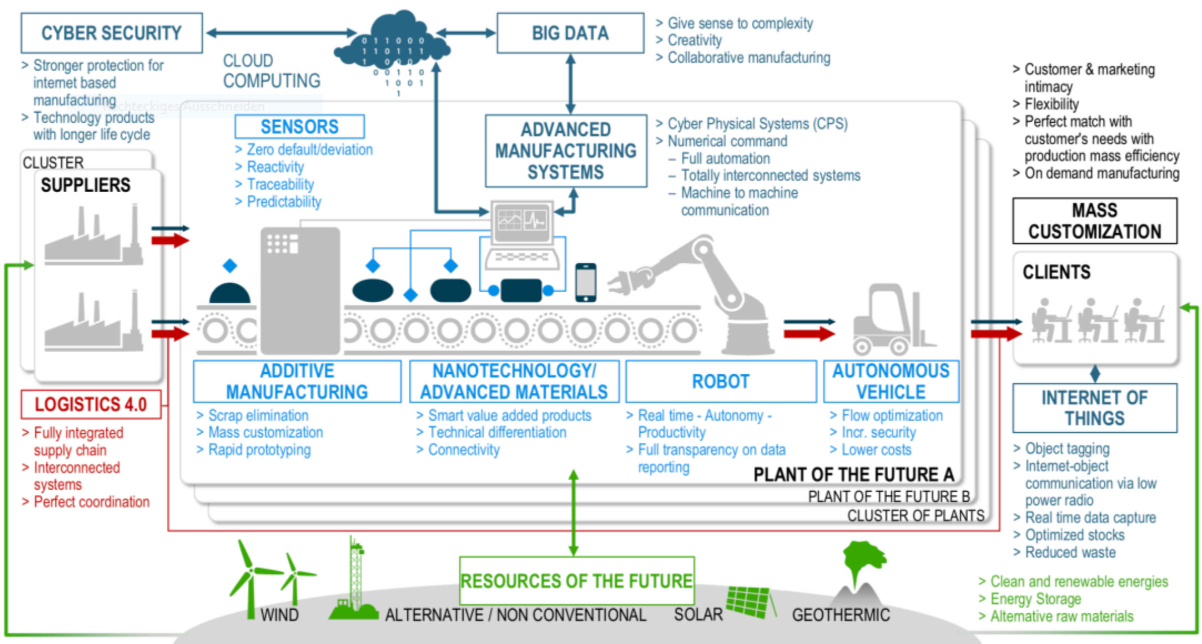

Figure 1: Evolution from M2M (machine to machine communication) to IoT, [6]

There are several definitions of IoT that vary in their focus and level of detail. In all cases, however, IoT involves uniquely identifiable, context-aware objects that are able to communicate with other objects and humans and perform autonomous operations to change their own state and that of their surroundings [7]. These new hybrid objects that combine the physical world with communication technology and information processing are called Cyber-Physical Systems (CPS). CPS combined with prescriptive and predictive analytics enable predictive maintenance in addition to process optimization. To do this, each digital device will need to be able to communicate its real-time status (the "digital shadow") to other devices, which can then make optimal decisions based on the information they receive. This will allow tasks to be prioritized, synchronized, and dynamically reconfigured, significantly reducing the need for quality inspections, and monitoring and thus costs in industrial manufacturing [8]. Similar or even greater advances can be expected in the domain of smart cities and buildings, as modern urban areas are responsible for approximately seventy percent of the world's energy-related emissions [8].

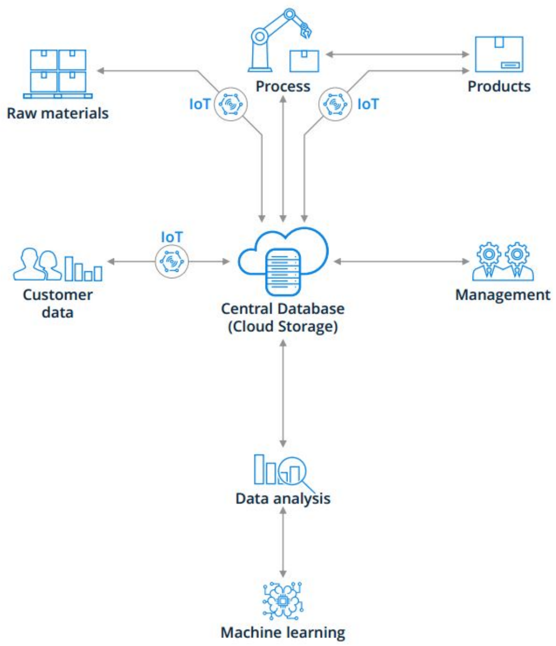

Figure 2: An IoT industrial system illustration, [9]

The spectrum of IoT and its application in an industrial context (Industrial IoT) is very broad and includes not only (semantic) web technologies and IP-based protocols, but also technologies for semantic representation and exchange of data and information in automation-related areas. The ability to integrate other technologies and already existing "legacy" protocols into a seamless, coherent and networked entity is crucial. The concepts and goals of Industrial IoT and its paradigms and of cyber-physical production systems (Industry 4.0) are described. For this purpose, a compact overview of traditional standards and future developments in the field of communication and information modeling in the automation environment is given. The focus is on functional models and data, as these will have the greatest influence on the quality of the implemented systems. They can therefore be seen as a common denominator for all associated domain-specific representations.

3.1.2. Zotero literature collection

As part of the international project, a large number of literature sources were collected in a public Zotero group, available at this link:

https://www.zotero.org/groups/4871439/annex56/library

This collection provides an overview of the current state of research on IoT technologies for heat pump systems. The resources include literature material on the different types of IoT devices and sensors used in heat pump systems, as well as the benefits and challenges of IoT integration. In addition, the Zotero library contains papers and articles on the latest research on IoT-enabled control strategies, optimization algorithms, and predictive maintenance for heat pump systems.

3.1.3. Security and data protection by design and by default

Data security and data protection play an important role in the development of IoT-enabled heat pumps. New applications and business models are emerging that are based on IoT-enabled heat pumps and focus on data processing. The importance of data security has long been recognized in this area. Users generally rely on their heat pumps to heat their homes or keep production processes running. However, the long technical life cycle of heat pumps combined with the shorter life of electronic devices requires special considerations. For example, technical standards that are widely used today may no longer be available during the life cycle of a heat pump. The world of consumer electronics and home automation has changed dramatically over the past 20 years. As technical and security standards evolve, it will be necessary to provide secure update mechanisms that allow systems to be updated quickly while remaining easy for users to operate. This includes, for example, planned renewal of the server infrastructure to ensure that users remain in control of their heat pump systems throughout the product lifecycle.

Heat pump usage data can also provide information about the environment in which they are used. For example, in residential buildings, building occupancy can usually be derived by heating patters. Protecting this information is particularly important because it can easily be misused by burglars or stalkers, for example. Even if the systems use technical identifiers that are only used to identify the heat pump, it is usually possible to identify the user behind the heat pump. Privacy is therefore an important issue for these systems. Data protection is a property of the overall system and not just of individual components. Close cooperation between OEMs and suppliers is therefore necessary to ensure effective protection of user privacy. An important strategy for achieving this goal is data protection through technology design and through data protection-friendly default settings. This involves taking data privacy into account from the outset of system design and selecting the most privacy-friendly default settings without requiring user intervention.

Data privacy and data security should be evaluated not just once, but regularly during the life of the project to ensure that the analysis remains up to date. Data protection and data security are not just technical procedures, but a property of the overall system. They include both organizational and technical measures. Therefore, external suppliers, third-party software, and internal procedures used for data processing must also be considered. Only when the entire lifecycle of the system is taken into account can data protection be achieved through technology design.

The Task 1 report discusses data privacy and data security in detail. There is also a collection of heat pump-specific questions and answers for manufacturers of IoT-enabled heat pumps.

3.1.4. Factsheets for IoT enabled heat pumps

This section provides a collection of specific IoT use cases involving the design, development, and implementation of IoT solutions for heat pump systems. These use cases were gathered in the national projects contributing to this Annex. They cover both market available IoT products and services related to heat pumps and ongoing, planned or recently finished research projects in that field.

For each use case, all the information is summarized in a dedicated factsheet that is available on the IoT Annex website. Furthermore, a framework was established to structure and summarize information from the use cases. The aim of the framework is to achieve a consistent description of all important aspects, ranging from stakeholders, participants, connection and data requirements, perceived benefits to technological readiness (see Figure 3).

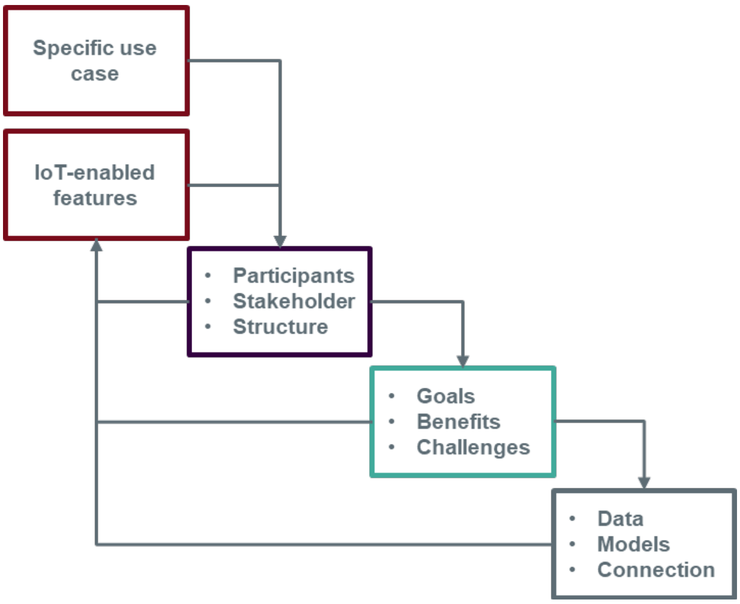

Figure 3: Framework for structure and describe use cases for IoT-enabled heat pump products and services

Based on the framework, common patterns are found among the use cases that result in the description of the following main IoT categories: heat pump operation optimization, predictive maintenance, flexibility provision, heat pump operation commissioning, heat as a service. A use case can fall into more than one IoT category.

Heat pump operation optimization: The optimization of heat pump operation is crucial for maximizing energy efficiency and reducing energy costs. IoT technologies can be used to continuously monitor and analyze heat pump performance, allowing for real-time optimization and adjustment of operation parameters. By optimizing heat pump operation, building owners and operators can reduce energy consumption and improve system performance, resulting in cost savings and environmental benefits.

Predictive maintenance: Predictive maintenance is an essential aspect of ensuring the longevity and reliability of heat pump systems. IoT-enabled sensors can continuously monitor system performance and provide real-time data on system health. By analyzing this data, predictive maintenance algorithms can identify potential issues before they become critical, allowing for timely and cost-effective maintenance interventions. By implementing predictive maintenance strategies, building owners and operators can reduce downtime, extend the lifespan of heat pump systems, and optimize maintenance costs.

Flexibility provision: Flexibility provision refers to the ability of heat pump systems to provide flexible energy services to the grid. By incorporating IoT technologies, heat pump systems can be configured to operate in a way that provides maximum flexibility to the grid. This can include adjusting the timing and level of heat production in response to grid demand, as well as providing ancillary services such as frequency regulation. By providing flexibility to the grid, heat pump systems can help to stabilize the electricity system, reduce energy costs, and facilitate the integration of renewable energy sources.

Heat pump operation commissioning: Commissioning is a critical aspect of ensuring the safe and effective operation of heat pump systems. IoT technologies can be used to streamline the commissioning process, allowing for faster and more accurate system setup. By using IoT-enabled commissioning tools, building owners and operators can ensure that heat pump systems are configured to operate optimally from the outset, minimizing energy consumption and optimizing system performance.

Heat as a service: Heat as a service is an emerging business model that aims to provide heat pump systems to customers as a service rather than as a product. This model can help to overcome some of the barriers to heat pump adoption, such as high upfront costs and technical complexity. By implementing IoT technologies, heat pump service providers can remotely monitor and optimize system performance, ensuring that customers receive high-quality, reliable, and cost-effective heating services. Heat as a service can help to accelerate the adoption of heat pump systems, enabling more buildings to benefit from the energy and cost savings they offer.

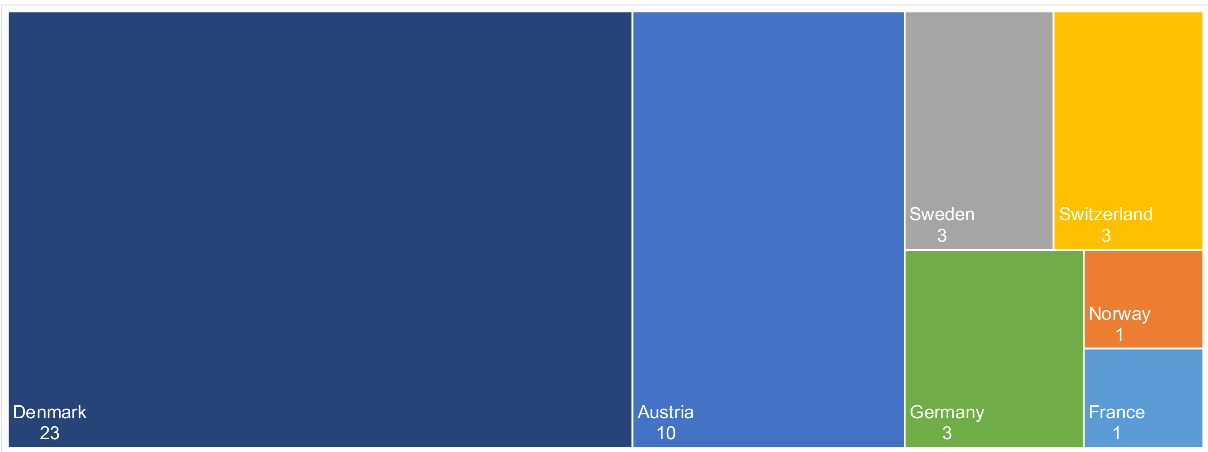

Figure 4: Distribution of 44 use cases by country

In total, 44 use cases were collected, thereof 19 products and services and 25 research projects. Most of the use cases were provided by the Danish team (23 examples), followed by Austria (10), see

Figure 4. On the Annex website, all factsheets are available, they can be browsed by country, by TRL (project or product) and by IoT category.

3.1.5. Market overview, survey and interviews

Denmark Review of the status of Digitalization and IoT for Heat Pumps

A total of 23 examples were analysed that are available on the Annex website. The collected information from both product and service suppliers and R&D projects in Denmark shows that several stakeholders at different levels in the heat pump industry are focusing on enhancing and deploying digital and IoT-enabled solutions for heat pumps in Denmark. There are overlaps with companies being present in more groups, but in general the suppliers and service providers in this review can be grouped as follows:

- Heat pump manufacturers: Energy Machines, Johnson Controls, DVI, and METRO THERM
- Aggregator: Neogrid Technologies
- Service Provider: Climify, Centrica, ENFOR, EnergyFlexLab, AI-Energy
- End-user: HOFOR, Nærvarmeværket
- OEM: LS Control
- Datahub: Center Denmark

In addition to this the participants in the Danish national Annex project are aware of various other companies in Denmark working on digitalization and IoT solutions, who did not directly give input to the review. The groups have different roles and interactions between each other, which is visualized in Figure 5. The figure shows a general setup for an IoT-based energy system around heat pump(s) and the involved groups, but it must be emphasized that there are also other possible setups depending on the specific use case.

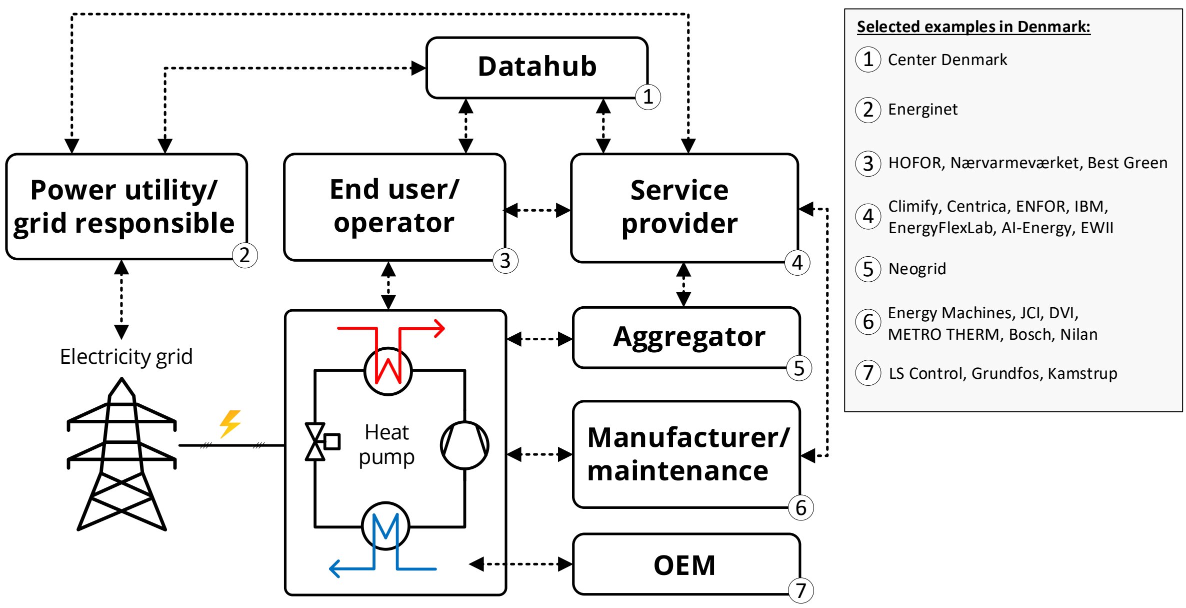

Figure 5: Visualization of supplier groups and examples of associated suppliers in an IoT-based energy system for heat pumps.

In Denmark there are strong incentives to install heat pumps to reduce the dependency of the heating sector on fossil fuels and leverage the increasing amount of renewable (fluctuating) power in the electricity grid, of which the average annual share in Denmark was 47 % in 2021, [10]. Regarding the electricity price different tariffs applies depending on what time of the day it is. The tariff comes on top of other costs such as the spot electricity price and taxes. Furthermore, most Danish electricity providers offer their customers to pay hourly adjusted prices, which are settled according to the tariffs and hourly marked spot prices. If the primary heating installation is operating on electricity the consumption above 4,000 kWh for a household can get a reduction in the tax cost for electricity, [11]. These measures incentivize the use of smart controls and digital solutions, enabling a high potential to integrate the heating and power sectors by using heat pumps.

In this context, a number of technology suppliers such as Neogrid, Centrica, AI-energy, ENFOR and METRO THERM, offer solutions towards the use of heat pumps for sector integration. Here, the most common type of solution is the remote or local adjustment of the heat pump operation based on measured and/or forecasted electricity prices. This enables a reduction of operational costs for users by the use of available low-cost renewable energy resources and the avoidance of periods with limited power supply.

The provision of flexibility through heat pumps is also possible with some of the technologies currently available in the market. However, in the case of residential heat pumps an aggregator is needed to pool a number of heat pumps, which may raise data security concerns. In the case of district heating heat pumps, their flexible operation has e.g. been analyzed in an R&D project.

Predictive maintenance of heat pumps complemented by IoT-enabled technologies is already available in several technologies offered in Denmark. This includes the solutions offered by Energy Machines, LS-Control, Neogrid, Nærvarmeværket and METRO-THERM. Remote predictive maintenance enables the reduction of operation and maintenance costs by decreasing the number of times that a heat pump requires the physical assistance of a service technician and by taking preventive measures before it is not possible to avoid or mitigate the negative effects of faults in the heat pump components. R&D projects have also aimed at developing predictive maintenance solutions by means of digital tools. In this case, the technologies under development include digital twins, where the potential effects of fouling can be analyzed and predicted based on adaptive model-based frameworks, as well as advanced data-driven methods that are able to describe and predict the effect of faults by means of real-time measured data.

Accessible data is one of the key elements needed towards the development of digital solutions supporting the sector coupling between electricity and heat sectors. The present review indicated that the digital data platform from the company Center Denmark is used for such a purpose in several projects. The data platform gives consumers in Denmark a direct opportunity for sharing energy consumption and operational data with Center Denmark, and hereby facilitating the development of energy-efficient data solutions in a secure and reliable manner. Service providers or other stakeholders can then purchase anonymized data to develop their solutions. Currently, tens of thousands of Danish households are taking part in this scheme, where e.g. data on electricity, heat, water, and indoor climate are shared.

Especially in the R&D projects, a number of different tools for numerical modelling of heat pumps were identified. This includes approaches such as white-box or physics-derived models, black-box or data-driven models, and grey-box models. The white-box paradigm is often applied when a model is required in the design of a system and/or its components, or to analyze the performance of a system and certain phenomena that can be described straightforwardly with physics. Contrarily, black-box and grey-box models are likely to be applied when simplified representations of reality are sufficient or when it is needed to analyze operational conditions that are difficult or impossible to predict by physically-derived representations, such as faults and performance degradation. Digital twin frameworks, which are under development in multiple R&D projects may integrate different types of modelling approaches, depending on the data availability, type of service, and communication constraints, among other factors.

It was identified that different stakeholders will need to interact (fast) through different interfaces, e.g. over API interfaces, Modbus, MQTT, end-user apps, and fog/edge-based computing facilities. This shows that the industry could overall benefit from making standardized interfaces to avoid having various suppliers using and developing each of their own. More standardized interfaces could e.g. include monitored data from the heat pump and the heat demand, but also electricity and heating prices, leading to further possibilities for incorporating comparison schemes between technologies in control and monitoring digital interfaces. Current general issues with this includes a lack for standards across countries, e.g. within the EU, particularly on how price signals shall be communicated to the heat pump. Challenges for those standards include considerations about where to best locate price forecasts, what format it should have, what should be the cost for access, which areas should be included, and who exactly should control the heat pump without compromising its lifetime? Is it the grid system operator, aggregator, or heat pump manufacturer? The definition of such standards may contribute to answer those questions and may advance towards the improvement of operation of heat pumps and energy systems.

In Denmark there are various industry communities working with the energy system. An example of this is "Intelligent Energi" (https://ienergi.dk/) which is a community for stakeholders who work with advancing an integrated and flexible energy system that provides Danes with safe and green energy at competitive prices. Intelligent Energi supports this development by working on more uniform framework conditions for by being a platform for collaboration within and across electricity, gas, water, and heat sector, and hence also how to best include heat pumps in the energy system.

France: Market report

AFPAC, the French heat pump association published a study on the heat pump of the future in 2019 under the title "Heat pump of the future: smartness and connectivity". This study covers topics such as the ideal heat pump, hybrid solutions, waste heat recovery, flexibility, smart technologies, data management and network interactions, [12].

This report distinguishes between smart and connected heat pumps. The definition of a smart heat pump describes a device used to provide heating and/or hot water and/or cooling in a building and focuses on comfort, efficiency, and minimizing environmental impact. It adapts its operation to various factors, such as building and user comfort, thermal conditions (indoors, outdoors, heat source), demands or signals from the power grid (utility, grid operator), the operation of other heat generation systems or local power generation, as well as the status of heat storage and the heat distribution network. It also provides real-time information to users to optimize heating, cooling, and hot water production while ensuring easy commissioning, ease of use, performance optimization, cost efficiency, and maintenance, see Figure 6.

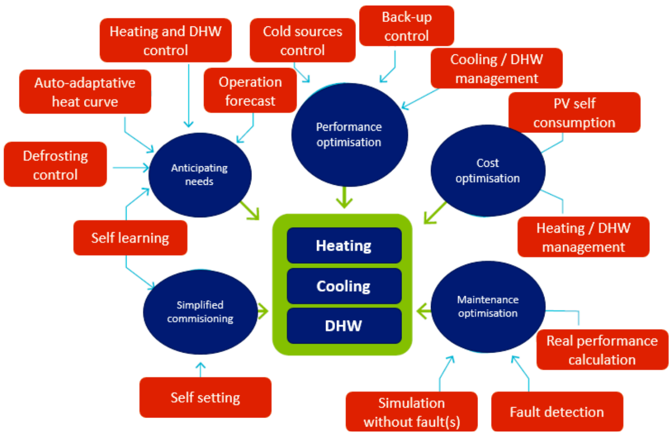

Figure 6: Functions fulfilled by a smart heat pump

IoT enabled heat pumps have communication facilities and are connected to the Internet. They act as part of a networked environment. These heat pumps can be controlled via apps on the smartphone and offer a range of services, such as incorporating weather forecasts, or adapting the operation of the heat pump to the presence and absence of the users, as well as third-party services. An open policy for data sharing and exchange is desirable.

The heat pumps of the future will first be smart - meaning able to deliver comfort without interruption and communicate with end users - and then be networked. That means they will be able to communicate with the grid or with other "things".

Austria: Manufacturer survey

A survey was conducted on the importance of IoT among companies in the Austrian heat pump industry. The survey is based on a comprehensive questionnaire designed by experts for heat pumps. The questions cover various aspects, such as company size, organization and market activities, availability of specific digital technologies and products, such as hardware and software, communication interfaces, data security, data analysis, availability of specific applications and services, and collect general feedback on motivation for IoT technology adoption, relevant market and customer needs, challenges, current issues and trends in this field.

The companies were contacted by the Austrian heat pump association "Wärmepumpe Austria" (WPA) and asked to participate in the survey. The WPA covers the entire value chain of the heat pump industry in Austria and includes not only heat pump manufacturers in Austria but also all electricity supply companies, component suppliers and drilling companies, as well as planners, installers and engineering companies. Answers were collected from May to June 2022. The survey included more than 50 questions, including single- and multiple-choice questions, rating and ranking questions, and free-text questions. The survey took an average of about 20 minutes to complete.

The survey was successful. Participating companies represent 53% of Austrian heat pump manufacturers and 27% of heat pump dealers, allowing for meaningful results. To a lesser extent, component manufacturers and installers participated. The participating companies are small as well as medium and large enterprises. All companies offer residential heat pumps, and some companies also offer products for the industrial and district heating markets.

The companies generally attach great importance to the development and use of IoT solutions. All companies offer both IoT products (e.g., heat pumps with connectivity or smart components such as compressors or sensors) and services based on IoT products (e.g., PV or price optimization, product improvement and development). Two-thirds of the products assessed are available, i.e., either in their product portfolio (in implementation) or already in use in large numbers (extensive implementation). Another third is currently under evaluation, in development, or in a pilot phase.

The self-assessment and comparison with international competitors show that two companies see themselves as pioneers in offering IoT products. The remaining manufacturer responses tend to be conservative, with eight seeing their products as state of the art and six companies seeing a need for development. When it comes to the use of IoT services and business processes, the feedback is very similar, one company sees itself as a pioneer, seven are at the state of the art, and eight see a need for development.

When asked about the motivation for introducing IoT products, the three most frequent answers were customer loyalty, service improvement and new business models (see Figure 7). In addition, certain IoT products and derived services are explicitly desired by customers. Cost reduction was ranked higher than environmental considerations. For most companies, IoT products are not seen as a particularly unique selling proposition.

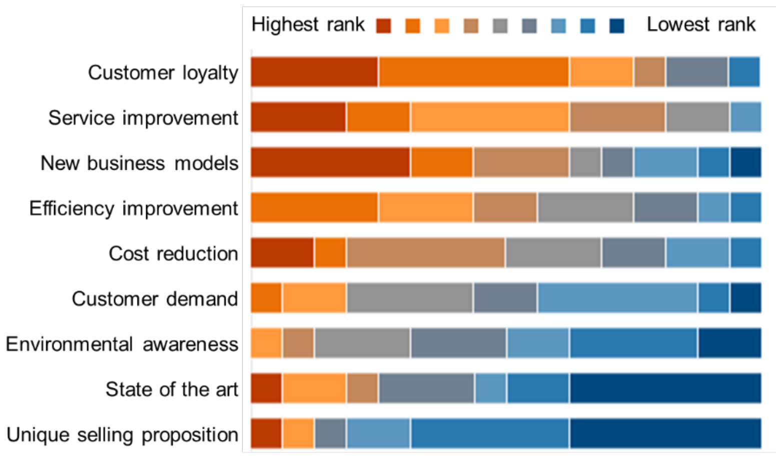

Figure 7: Motivation to introduce IoT products

The participating companies also see that the use of IoT technology can bring about significant changes. These are expected primarily in product development, business models, maintenance and, in some cases, sales. Lesser or insignificant effects are expected in the customer segment, production, installation and supply.

IoT technology is only one of several digital transformation technologies that are considered to be of high importance for the future, see Figure 8. Equal or similar importance is attributed to machine learning, predictive maintenance and building information modeling. Privacy requirements are ranked neutrally. In contrast, asset administration shell, semantic modeling and digital twin are considered as less important.

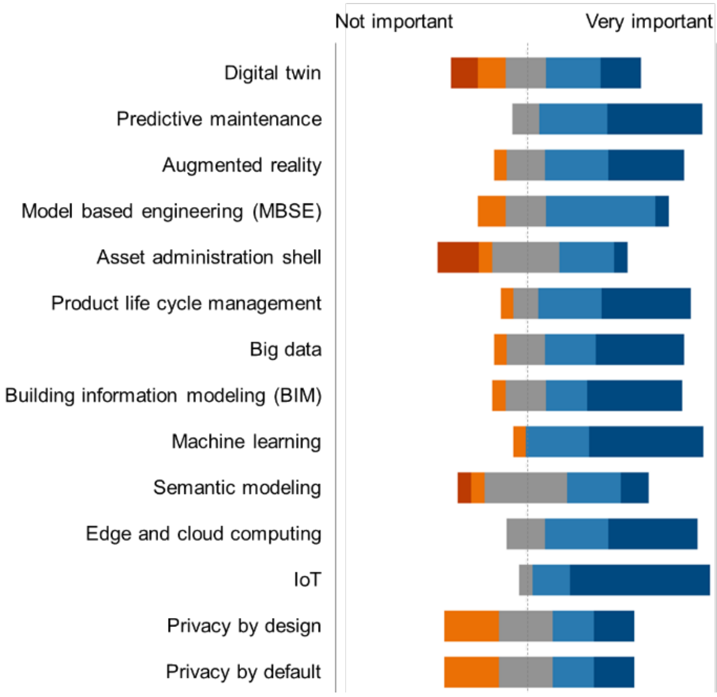

Figure 8: Importance of digital transformation technology for the future

The survey shows that companies do not have a uniform strategy for handling and processing data. While almost all companies state that operational data is collected, there is no clear preference in terms of storage and accessibility for users. Local and cloud solutions are rated as equally important, with most offering both options. For example, for residential heat pumps, 50% use both local storage and the cloud, 31% use the cloud, and 13% use only local storage.

Field data collected included state of the art heat pump measurements, i.e., supply and return temperatures, electrical power, source temperatures, heat output, switch cycles, set points, and part load condition. They were mentioned almost equally often by all companies (minimum 10, maximum 13 mentions). The use of data goes beyond just collecting and storing data locally and in the cloud. Only two companies state that the collected data is not currently processed or analyzed. The companies surveyed are applying advanced methods for industrial automation, data processing and analysis, and user interface design and implementation on various platforms. Various monitoring and control applications are offered, aimed at improving efficiency, detecting anomalies and monitoring operations, detecting installation faults, and providing an improved or new service offering. Most often, more basic data analysis methods are used, such as visualization and monitoring of real-time data and calculation of key performance indicators (KPIs), statistical analysis based on historical data. Advanced data analysis methods (such as automatic pattern recognition based on machine learning) were less frequently reported. While Modbus is still the predominant communication protocol in heat pump automation, companies also offer other protocols, such as KNX, OPC UA, or BACnet. The collected data is usually not shared directly with customers. Companies are aware of data protection requirements and follow standards and regulations for security measures.

Most often, IoT products and services are developed by project teams or by a part of the development department. The main barriers to IoT technologies are availability of qualified personnel, data protection and legal requirements, and lack of standards. Communication protocols and interfaces as well as the availability of suitable hardware are seen as less critical.

The general expectation, shared by all companies in the survey, is that IoT technology will bring significant changes. It is expected that IoT-enabled heat pumps will be a part of networked systems rather than an autonomous smart component. In this context, IoT technology is seen as one of several important digital transformation technologies for the future.

Sweden: Expert interviews

Interviews were conducted with leading heat pump manufacturers, IoT companies, associations, and consultants in Sweden. The aim of the interviews was to gather information about the current trends and challenges in IoT-enabled heat pumps, as well as the opportunities and potential benefits of integrating IoT technologies into heat pump systems. All responses highlighted the importance of IoT technologies for heat pump system connectivity. Using IoT technologies, heat pumps can be integrated with a range of monitoring and maintenance services, enabling real-time data analysis and predictive maintenance. In addition, IoT technologies can enable communication between the heat pump and other devices in the building, such as smart thermostats or energy management systems, allowing for coordinated and optimized operation.

Interconnection of heat pumps from different manufacturers: The responses show that there are challenges in connecting heat pumps, both between different manufacturers and within the product range of a single manufacturer. These challenges are primarily related to compatibility issues and a lack of standardization in the industry, making it difficult to develop a truly networked and efficient heat pump system. However, as the industry evolves and standardization efforts gain momentum, it is likely that these challenges will be resolved.

Objectives of IoT solutions for heat pumps: In the interviews, the most important objectives of IoT solutions for heat pump systems were prioritized as follows: reduction of operating costs, improvement of service and repair, emissions and environmental goals, increased indoor comfort, reduction of capital costs, user engagement. The highest ranked goal of "reducing operating costs" is a major concern for many users and stakeholders, as it can lead to significant savings in energy bills and maintenance costs over time. IoT solutions can help achieve this goal by enabling real-time monitoring and control of heat pump systems, optimizing their performance, and identifying potential problems before they become major issues. The second-place goal, "Improvement of service and repairs", shows the importance of ensuring that heat pump systems are reliable and easy to maintain. IoT solutions help by providing remote diagnostics, predictive maintenance and other features that help reduce downtime and ensure the system is always working at its best. The third-place goal, "Emissions and Environmental Goals," highlights the increasing importance of sustainability and environmental responsibility in the design and operation of heat pump systems. IoT solutions can help meet this goal by providing data on energy consumption, emissions, and other environmental impacts, and by supporting the integration of renewable energy sources and other sustainable technologies.

Future challenges: IoT has the potential to address a number of important challenges associated with heat pump systems, including data security, privacy and property rights, the often low operating cost reduction of current solutions, and the lack of standardization. By leveraging advanced data analytics and machine learning algorithms, adopting clear standards and protocols for device connectivity and interoperability, and implementing advanced security protocols and encryption technologies, IoT can help maximize energy savings, improve heat pump system efficiency, and support the development of a more sustainable energy system.

3.2. Links between Task 2, Task 3, and Task 4

Task 2 (interfaces), Task 3 (data analysis) and Task 4 (IoT business models) are closely linked: An application or service that creates added value with the help of an IoT heat pump or a connected heat pump component can be described by a complete cycle of data collection, data processing, inference and action based on this. The cycle is illustrated in Figure 9. Similar concepts exist, for example, in quality control in business management with the PDCA cycle (Plan-Do-Check-Act) or in military decision making with the OODA cycle (Observe-Orient-Decide-Act).

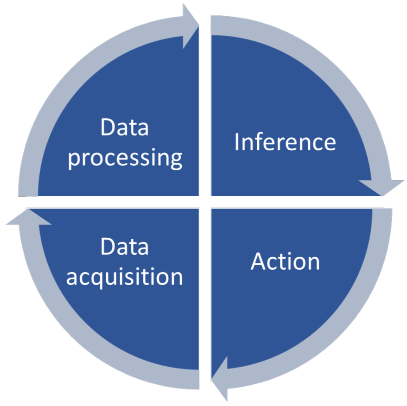

Figure 9: Decision making framework of an IoT application

In many cases, however, the feedback loop consisting of conclusion and action can be weak, long-term, and indirect. For example, data analysis may influence the design of future generations of heat pumps or human behavior based on visualized data, and therefore has no direct impact on heat pump operation. In other cases, such as digital twins for heat pump operational management, the loop may be clearly defined and fully automated. Without closing the loop, no added value, such as revenue, energy savings, comfort gain, etc., can be expected from an IoT application. A service or application can have several subcomponents, which in turn are services or applications. An example would be predictive maintenance using digital twins, which is built on periodic cycles for target/actual comparison.

Task 2 describes the communication structure needed to perform the data analysis discussed in Task 3, which in turn is driven by the business models described in Task 4.

3.3. Task 2 – Interfaces

In the international Task 2 report, the following topics are presented based on specific use cases: Digital twins of heat pumps, Connected heat pumps in building automation, Heat pumps in grid services and Retrofitting. The examples presented are either commercially available or part of research projects. Based on these examples, common challenges and possible solutions are elaborated.

3.3.1. Digital Twins of heat pumps

Four examples of Digital Twins are described in detail:

- DIGIBatch: a digital twin for predicting operating points for test bench measurements of heat pumps (research project from Austria)
- Distributed Digital Twin: Architecture of a distributed digital twin for large heat pumps and chillers (research project “Digital Twins for Large-scale Heat Pumps and Refrigeration Systems“ from Denmark)
- DZWI: Digital twin of heat generating systems as a pioneer for the development of low-emission building energy technology (research project from Germany)
- Digital twins by EnergyMachines (IoT product from Denmark)

The four examples address different aspects of integrating digital twins for heat pumps. The digital twin of a single heat pump providing a single service is analysed, as well as multiple services of distributed heat pump systems and their digital representations, and general frameworks for energy components. It is clear from the examples that the services around digital twins of heat pumps can have very different requirements, e.g. real-time control as opposed to predictive maintenance. Also, many of the aspects addressed in the examples are not purely specific to heat pumps but are general IoT issues - such as security. Digital twins are bespoke, either because of constraints imposed by a subsequently digitized infrastructure or because of different levels of integration in which they are used (for example, for control, for maintenance, etc.). This suggests the use of generalized frameworks that aim to simplify the creation, use, and management of digital twins and make them scalable, reproducible, and applicable to other components of a heat pump environment. In addition, such frameworks enable shared management of meta data and engineering data, which in turn facilitates the use of digital twins across the lifecycle and different use cases.

Different services and different levels of integration lead to specific requirements for data, models, and simulations, which in turn bring requirements for databases, simulation environments, and computing power. The use of centralized message brokers such as MQTT enables the distribution of data and tasks between field and cloud applications or services, they are therefore common in the collected use cases. Other commonalities include the use of high-level programming languages, particularly Python, and models based on the functional mock-up interface called FMU. Reusability and ease of deployment are the main reasons for using FMU.

3.3.2. Connected heat pumps in building automation

Two examples are presented:

- Energetikum: building a data-driven maintenance strategy for the Energetikum living lab, an office and research building (research project from Austria).
- ZEB Laboratory: integrating heat pumps and other building automation devices with a time-series platform to perform consistent analysis and develop services that optimize heat pump operation and the use of on-site generated electricity and heat storage (research project from Norway)

The connected heat pump as part of a building automation system is the subject of the two use cases. Although digital twin considerations are also applicable here, additional challenges arise from the environment in which the heat pump operates. Typically, building automation systems are very heterogeneous and include numerous small individual sensors and complex system interrelationships, and the amount of data collected can become very large. With this variety of system components, interoperability can be a challenge, as each vendor prefers different interfaces and protocols. This makes integration complex, while also considering that some of the data is sensitive personal data. The need to represent and connect different data sources in a consistent way entails the importance of semantic enriched data representation and protocols.

In the two examples presented, this is addressed by using BACnet/IP, although for streaming large amounts of data, MQTT is preferred due to its lower overhead. Gateways are used as the link between the various actors and the numerous automation protocols and higher-level analysis and control logic. Unfortunately, configuration and deployment of the gateways can be very effortful.

3.3.3. Heat pumps in grid services

Two examples are discussed:

- SLAV: communication of heat pumps with transmission and distribution grid operators (research project from Sweden)
- tiko: virtual power plant by pooling different consumers, including heat pumps (IoT product from Switzerland)

In these examples, the supplier providing flexibility is an external entity. This means that either additional effort needs to be put into interconnectivity by developing international standards, as described in the SLAV example, or by pooling everything into a single solution, as in tiko. This effort is necessary to create an environment where service providers can offer reliable business models for several years. As this involves public energy infrastructure and sensitive personal data, security is also of paramount importance. The typical separation of these use cases into lay customers - who typically have minimal involvement in implementation and operations - and expert service providers increases the challenge of ensuring data and metadata quality and completeness.

Gateway devices that connect various (existing) hardware in the field via the Internet are at the centerpiece of such use cases. In the home, WiFi is the most widely used interface to provide connectivity, enable over-the-air updates, and user engagement.

3.3.4. Retrofitting

Two examples are presented:

- SmartGuard: remote diagnostic tool for heat pumps (IoT product from Switzerland)
- AI4CITIES: monitoring of district heating (research project from Germany)

Given the longevity of heat pumps, the challenge is that computing platforms, interfaces and protocols must continue to run reliably and safely over a decade later. Furthermore, with reliability and existing knowledge in mind, manufacturers currently often prefer older, more established interfaces and protocols over newer IoT protocols. This is reflected in the fact that MODBUS is one of the most commonly used protocols.

Here, a layered approach to heat pump connectivity is most prevalent. In this approach, gateway devices connect the field level to the Internet, subsequently adding additional elements to the core functionality of the heat pump. Analysis and control can be performed either on the gateway device itself (edge computing) or externally (cloud computing). In many cases, this structural separation between the field and analysis levels is also reflected in the application or service built on top of it in the case of retrofits. This means that the core function of the heat pump is usually not automated, but only indirectly influenced by a human - who uses the insights from the collected data. The lack of pre-existing on-site connectivity often makes the use of wireless protocols and interfaces an obvious choice for retrofit applications. Further, the use of proprietary and non-standard interfaces, protocols and platforms on the field level is the biggest challenge to overcome.

3.4. Task 3 – Data Analysis

The international Task 3 report provides an overview of data analytics for IoT-enabled heat pumps. The goal of data analysis is to make sense of the collected data in order to provide targeted information, e.g., for the optimized operation of heat pumps as for example illustrated in Figure 10.

Based on the examples of IoT products and services presented in Task 1, different targets for data analysis are derived. Data analysis methods are categorized and evaluated, ranging from visualization and manual analysis to machine learning algorithms that learn from past user behavior to optimize heat delivery, or Big Data methods that learn from a large number of heat pumps how certain heat pumps perform compared to others and how they can be improved.

In addition, the report presents best practices on pretreatment of data and the use of data models, metadata and BIM (Building Information Modeling).

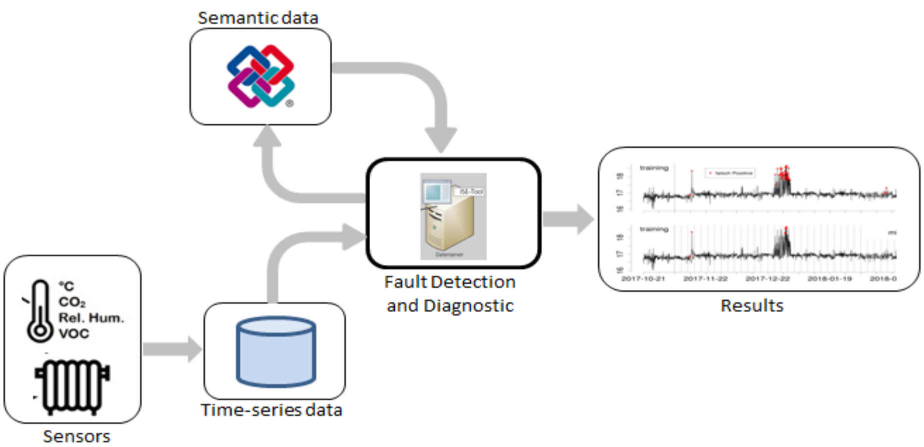

Figure 10: Illustration of data analysis for fault detection and diagnosis

The categorization of the analysis methods is based on the information about the use cases collected in Task 1. Not all descriptions were sufficiently detailed to be considered for analysis in Task 3, this is especially true for the descriptions of products. There are therefore 16 use cases considered in this evaluation, including three products (tiko, Smart Guard, Hi Kumo pro), the others being research projects.

In order to systematically evaluate the data analysis methods of the use cases, they are further categorized according to the aspects of the specific goal to be achieved by the analysis method and how these goals are achieved. This analysis objective usually coincides with the general IoT category of the use case. Then, each use case was assigned an IoT category, one or more analysis goals, and one or more analysis methods. Figure 11 shows the approach.

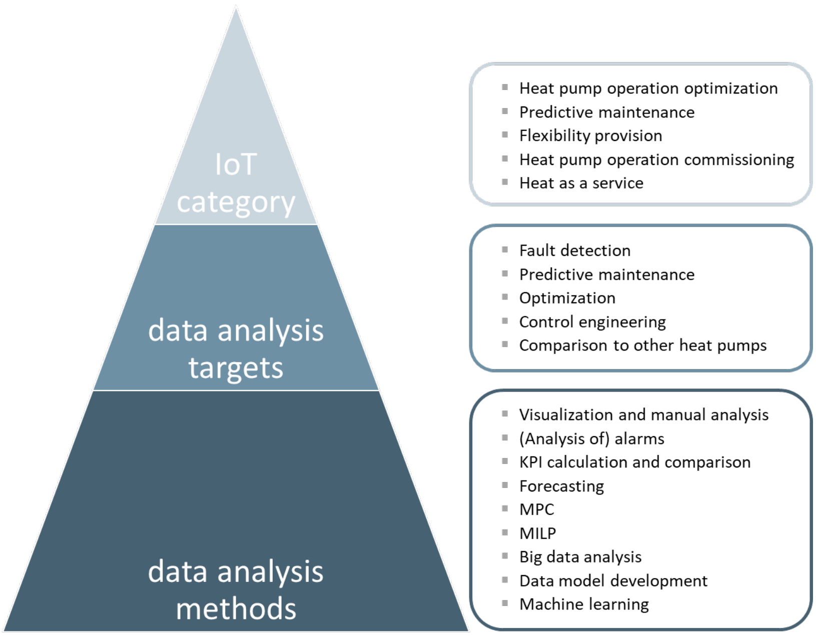

Figure 11: Hierarchy derived from the use cases: IoT category, data analysis targets and data analysis methods

Most use cases are assigned to a single IoT category, but often refer to different data analysis targets and data analysis methods. For example, the IoT category "heat pump operation optimization " can be done with "control engineering" and "comparison to other heat pumps" using "visualization and manual analysis" or "machine learning" as methods. During the categorization process, it became clear that it is not possible to explicitly distinguish between IoT category and targets and targets and methods.

As described in Task 1, there are five IoT categories that describe the different application areas of IoT products and services. "Flexibility provision" and "Heat as a Service" address more commercial applications. The remaining three categories deal with heat pump operation in different phases of a heat pump's life cycle, starting with "Heat pump operation commissioning " and "Heat pump operation optimization" and ending with "Predictive maintenance". In particular, the " Heat pump operation optimization" category covers a wide range of applications, from manually improving heat pump operation to using appropriate mathematical algorithms.

The intermediate level consists of five data analysis targets, some of which overlap with the categories and methods. For example, "Predictive maintenance" is defined as both a category and a target, as it can function both as a higher-level category and as a direct target of a specific analysis. The category "Heat pump operation optimization" largely overlaps with the target "Optimization", while the data analysis target "Optimization" is also related to "Predictive Maintenance" and "Commissioning of Heat Pump Operation". The data analysis target "Control engineering" covers a wide range of applications and is characterized by any kind of deviation in the heat pump operation from the originally set default control. Thus, "control engineering" ranges from simple on/off control of heat pumps to realize " Flexibility provision" to customized heat pump control for "operation optimization".

The derived nine data analysis methods consider methods at different levels, e.g. "(analysis of) alarms" and "machine learning". "Visualization and manual analysis", "KPI calculation and comparison" and "(Analysis of) alarms" methods are options of common preprocessing of measurement data. "Prediction" refers to any kind of prediction, e.g. data prediction or the presence of inhabitants in a house. "MPC" (Model Predictive Control), "MILP" (Mixed Integer Linear Programming), "Machine Learning" methods are standing terms and are applied as such. “Data model development" is listed here as a method of data analysis in the sense that the development of a data model typically needs to be done on parts of the application data. The resulting model could then contribute to all other data analysis methods.

When further comparing the targets of the data analysis methods with the IoT categories of the use cases, some insights can be derived. The two use cases in the "flexibility provision" category use data analysis methods with slightly different goals; one uses "MILP" to implement "optimization" while the other uses "big data analysis" for "control engineering". Thus, the methods used are appropriate for different levels of detail, which is also true for the models used. All six use cases that use data analysis methods aimed at "predictive maintenance" rely on "visualization and manual analysis" and "KPI calculation and comparison." Four of these use cases also target "fault detection." This makes sense, as fault detection and predictive maintenance are closely related. On the other hand, only two use cases also specify "Predictive maintenance" as an IoT category, while the others address "Heat pump operation optimization". All but one of the use cases in the "Operation Optimization" category use data analytics methods that also specify some type of "optimization" as target. These data analysis methods are also typically used for "control". The use of "forecasting" and "MPC" data analysis methods is a typical combination for this target, often through grey-box models.

Modeling and data analysis are key activities for IoT-enabled heat pump products and services, as they enable meaningful use of collected data to provide targeted information for desired purposes. Most of the data analysis information has been derived from research projects, as this information is openly available. However, this should not lead to the conclusion that data analytics is only used in research projects. There are many more IoT-enabled heat pump products and services where this information is not disclosed.

Detailed information on data analysis in all considered examples is available in the annex of the Task 3 report.

3.5. Task 4 – Business models

The Task 4 report provides an overview of IoT business models and market opportunities created by connected heat pumps. Based on the results of Task 1, 2 and 3, the most important use cases for IoT-enabled heat pumps are identified. Literature and market research are the basis for the overview of business models for connected heat pumps. For three business models, a detailed SWOT analysis was performed together with the Annex 56 group to identify strengths, weaknesses, opportunities, and threats.

3.5.1. Stakeholders

The analysis of the business models showed that several stakeholders are involved. In total, ten different stakeholders were identified: Heat pump manufacturers, component manufacturers, heat pump dealers, heat pump installers, users, operators, energy service companies, aggregators, suppliers, and the electricity grid. Figure 12 shows the tasks of the stakeholders in the life cycle of an IoT-enabled heat pump, Table 3 illustrates which stakeholders are involved in which of the IoT categories.

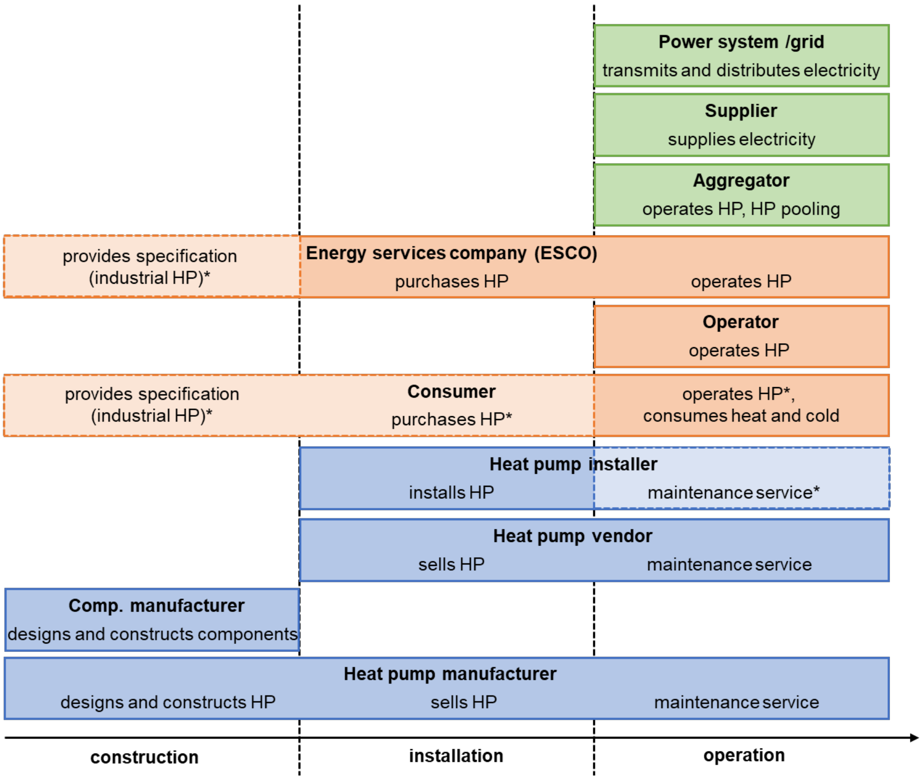

Figure 12: Overview on stakeholders in the life cycle of IoT enabled heat pumps (* indicates optional tasks)

Table 3: Stakeholder and IoT application matrix (x = involved, (x) = could be involved)

Stakeholder	Heat pump operation optimization	Predictive maintenance	Heat pump operation commissioning	Flexibility provision	Heat as a service
Consumer	x	x	x	x	x
Operator	x	x	x	x	x
Heat pump manufacturer	x	x	(x)	x	x
Heat pump vendor	x	x	(x)	x	x
Heat pump installer	x	x	x	x	x
Aggregator				x	
Power system/ grid				x	
Supplier	(x)			x	
Energy service company	x	x	x	x	x

Operation optimization also includes the interaction with energy suppliers and consumers at the site, where the heat pump is operated, as well as the integration in higher level systems (building energy management or industrial process control system). These interactions are in the responsibility of the one operating the heat pump (end-user or operator or ESCO).

Heat pump operation optimization, commissioning and predictive maintenance involve the traditional stakeholders in the heat pump sector: consumers, manufacturers, vendors, and installers. There is no difference between residential and industrial applications of heat pumps. By contrast, flexibility provision involves considerably more stakeholders related to the energy system. Aggregators are especially needed for small scale residential heat pumps, heat pumps with larger capacities can provide grid services without an aggregator. Heat as a service or heat contracting is offered by ESCO and is based on a different model of ownership of the heat pumps.

3.5.2. Examples for business models

Heat pump operation optimization

IoT services for operation optimization of heat pumps aim to save energy, emissions, and costs without compromising comfort requirements of the users. A basic version of optimization is monitoring and remote control via an app, that provides an overview on actual and historic data and allows for set point adjustment by the user. Advanced systems allow for adaption to user habits and for optimal interaction with other components e.g., to maximize self- consumption of PV production or solar thermal energy or the optimal management of a thermal or electric storage. Therefore, data analysis is typically carried out in the cloud of the service provider. Most commonly, operation optimization is offered together with other IoT applications, such as grid services or predictive maintenance.

- PreHEAT by Neogrid (IoT product from Denmark)
- myiDM+energy by iDM (IoT product from Austria)
- KNV (IoT product from Austria)
- METRO THERM (IoT product from Denmark)
- Centrica Energy (IoT product from Denmark)
- Neusiedl heat pump by Energie Burgenland (Austrian energy supplier)

Predictive maintenance

Predictive maintenance aims to plan maintenance as precisely as possible in advance and to avoid unexpected equipment failures. Thereby, downtime of equipment is reduced and unplanned shutdowns that typically cause costs, delays and discomfort are reduced. Also, resources for maintenance work such as spare parts and work force can be planned more precisely. Predictive maintenance requires condition monitoring of the equipment and data analysis to detect anomalies and failures. It can either focus on critical components of a heat pump e.g., the compressor or it can analyze the complete heat pump system. PreHEAT by Neogrid (IoT product from Denmark)

- SITRANS SCM IQ by Siemens
- IoT fans and ZAbluegalaxy Cloud by Ziehl-Abegg
- IQ compressors by Bitzer
- Energy Machines Verification Tool by EnergyMachines™ (IoT product from Denmark).
- Nærvarmeværket (Danish energy services company)

Flexibility provision

Heat pumps are well suited to provide flexibility to the power system, which is increasingly in demand as the amount of intermittent renewable generation increases. There are different types of flexibility available in the power system, with varying time scales (from 1 week to 1 second). The type of flexibility that can be provided with heat pumps depends on the characteristics of the heat pump system as well as the applicable national regulations.

- tiko (IoT product from Switzerland).
- Flex+ (research project from Austria)
- Green the Flex (research project from Austria)
- Flex Heat Project (research project from Denmark)

Heat as a service

Industry: Heat contracting business models already exist in the commercial and industrial sectors, where energy service companies (ESCOs) provide heating, hot water or process heat to industrial customers. Most typically, heat pumps with larger capacities are the subject of contracting, since it involves considerable effort for ESCO to set up and operate the heat pump.

- Kelag Energie und Wärme (Austrian contracting provider)
- Aneo Industry (Norwegian contracting provider)

Household: Heat as a service ranges from equipment leasing to a payment plan for heat. The service company takes over tasks that are normally carried out by the users themselves (purchase and installation of the heat pump, maintenance, efficient operation, etc.). The users pay for the provision of heat or comfort and do not have to take care of the system.

- Nærvarmeværket (Danish energy service company)
- Viessmann (German heat pump manufacturer offering leasing)
- Thermondo (German leasing provider)
- Energie Burgenland (Austrian energy supplier offering leasing)
- Energy Systems Catapult (UK research project on business models)

3.5.3. Conclusions

Business models for IoT-enabled heat pumps are already available and have been analyzed using numerous examples. The following aspects are essential:

The main benefits for users of IoT-enabled heat pumps are lower costs, more efficient heating systems and higher reliability.

For the heat pump value chain (component manufacturers, heat pump manufacturers, dealers, installers), digitalization leads to new products and services that make heat pumps more attractive and future-proof. Compared to traditional business models, they have more responsibility for the efficiency of IoT-enabled heat pump systems.

The energy system (aggregators, suppliers, power grid, etc.) has a high demand for flexibility provision to compensate for fluctuating renewable generation. Heat pumps enable sector coupling by linking the heat and power sectors and providing flexibility at different levels, which will be particularly relevant for the future.

Energy service companies (ESCOs) are a new player in the building sector but are already established in industrial contracting. They help in the diffusion of heat pumps, as their service reduces the involvement of the users.

3.6. Task 5 – Dissemination and reporting

Annex website

The most important dissemination channel is the Annex website:

https://heatpumpingtechnologies.org/annex56/

- Description of the participants
- Task reports
- Factsheets
- Slide deck and recording for the webinar on the results of the Annex

Networking with other Annexes and Tasks

As digitalization is a topic of increasing interest, collaboration and networking with other Annexes and Tasks in other TCPs was sought, where similar projects on digitalization are implemented. An Austrian study [13] analyzed the activities within the framework of IEA's technology collaboration and published the dataset to visualize interactions between TCPs and highlight collaborations of countries on individual topics. In summer 2020, digitalization was a topic in 9 Annexes or Tasks in 7 TCPs. Germany participated in 6 Annexes or Tasks, Austria, Denmark and Italy participated in 5 Annexes or Tasks. In total 25 countries are active on the topic of digitalization in the framework of the IEA.

Networking was done with the following Annexes and Tasks:

- IEA IETS Annex 18 (Digitalization, Artificial Intelligence and Related Technologies for Energy Efficiency and GHG Emissions Reduction in Industry)
- EBC Annex 81 on Data-driven Smart Buildings
- 4E IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment
- Users TCP
- IEA DHC Annex TS4: Digitalisation of District Heating and Cooling (Optimised Operation and Maintenance of District Heating and Cooling systems via Digital Process Management)
- IEA SHC Task 68 (Efficient Solar District Heating Systems)

Networking activities comprise presentations of the Annexes and Tasks in the experts meetings, as well as knowledge exchange on suitable dissemination activities and interesting reports. A short analysis of business models for IoT enabled heat pumps was included in a report of IEA DHC Annex TS4 (Digitalisation of district heating - A guidebook from the IEA technology collaboration programme concerning district heating and cooling, 2023).

Publications on IEA HPT Annex 56

T. Fleckl, The Internet of Things for Heat Pumps, Presentation, IEA CERT Thematic discussion on Energy Efficiency and Digitalisation, February 2020, Paris.

V. Wilk, IoT and heat pumps: opportunities and challenges, Presentation, European Heat Pump Summit, Nuremberg, 2021.

V. Wilk, R. Jentsch, T. Barz, C. Reichl, S. Hauer, B. Windholz, S. Knöttner, R. Hemm, J. Spreitzhofer, G. Music, G. Steindl, W. Kastner, H. Plank, C. Heschl, R. Partl, D. Ziermann, R. Stelzer, Digitalization and IoT (Internet of Things) for Heat Pumps (IEA HPT Annex 56), Presentation and Paper, 28. Tagung des Forschungsprogramms Wärmepumpen und Kältetechnik des Bundesamts für Energie BFE, 2022.

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Workshop on Digitalization and Artificial Intelligence for Heat Pumps and Refrigeration systems, 26th International Congress of Refrigeration, Paris, 2023:

- C. Vering: Applying machine learning to boost operating performance of heat pump systems.
- D. Rolando: Data-driven approaches for improving control and monitoring of heat pump systems.
- V. Wilk: IoT and digitalisation for heat pumps - opportunities and challenges

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Yang Song, Davide Rolando, Gerhard Zucker, Hatef Madani. Development and validation of data-driven soft sensors for heat pumps. Poster presentation at International Conference on Refrigeration (ICR), Paris, 2023.

V. Wilk, IoT enabled heat pumps - Case studies and market opportunities, Presentation, European Heat Pump Summit, Nuremberg, October 2023.

4. Conclusions

The results of Annex 56 provide a good overview of the risks and opportunities for connected heat pumps. 44 application examples were collected in the participating countries, which clearly show that IoT-enabled heat pumps and products based on them are already available on the market. Five categories can be assigned to the application examples: Heat pump operation optimization, Predictive Maintenance, Heat pump operation commissioning, Provision of flexibility and Heat as a service. For the user, this typically means operating cost and energy savings and increased operational reliability. For the energy system, the provision of flexibility is of particular importance, as it enables better use to be made of fluctuating renewable energy generation. Exchange and use of data plays an essential role in this.

Various interfaces and protocols for communication are available for networked heat pumps. Often, the connection to the Internet is wireless via WiFi and gateways that connect to the cloud, where data analysis services can be accessed. For heat pumps integrated into building automation, BACnet and Modbus are widely used. In the Austrian survey, Modbus and KNX Fieldbus, UPC UA and BACnet were frequently mentioned. The analysis of the Danish use cases illustrates that different stakeholders need to interact (quickly) at different levels and through different interfaces, for example, API interfaces, Modbus, MQTT, end-user apps, and fog/edge-based computing facilities. The Swedish work shows that interoperability is difficult between heat pumps from different manufacturers and even within a single manufacturer's product range. However, these challenges do not apply exclusively to heat pumps, but more generally to interconnected actors in the energy system. Interoperability and data availability will play an essential role in balancing generation and consumption in the energy system.

Modeling and data analysis are key activities for IoT-enabled heat pump products and services, as they enable meaningful use of collected data to provide targeted information for desired purposes. Five data analysis objectives were collected in the analysis, to which different methods can be assigned: Fault detection, Predictive maintenance, Optimization, Control, and Comparison with other heat pumps. The data analysis methods used in the application examples are visualization and manual analysis, analysis of alarms, KPI calculation and comparison, prediction, MPC (model-based control), MILP (mixed-integer optimization), big data analysis, data model development, and machine learning. The analysis points out that the application largely determines the data analysis method.

IoT-enabled heat pumps are already part of business models and new services. The main benefits for users of IoT-enabled heat pumps are lower costs, more efficient heating systems, and higher reliability. For the heat pump value chain, i.e. component manufacturers, heat pump manufacturers, dealers, installers, digitalization leads to new products and services that make heat pumps more attractive and future-proof. Compared to traditional business models, this also gives them more responsibility for the efficiency of IoT-enabled heat pumps. The energy system (aggregators, suppliers, power grid, etc.) requires flexibility to balance fluctuating renewable generation. Heat pumps can provide flexibility and enable sector coupling by linking the heat and power sectors, which will be particularly relevant for the future. Energy service companies (ESCO) are a new player in the building sector (heat as a service, leasing of heat pumps, heat as a service), they are already established in the industrial sector with heat pump contracting. ESCOs can support the further diffusion of heat pumps, as users in contracting models do not have to deal with the heat pump, but only purchase the heat.

The importance of digitalization for the energy transition has increased further in recent years. Intelligent, digital solutions are increasingly in demand to make efficient use of various flexibility options such as electricity-based heat generation, the use of storage or e-mobility, and to control the power grid securely. Therefore, connected heat pumps will also play an important role in the future energy system. Current efforts of the latest EU action plan to develop a sustainable, cyber-secure and competitive market for digital energy services and digital energy infrastructures underline this. Important fields of action are the definition of common standards and the improvement of the interoperability of devices in the energy system. A common European energy data space for the exchange and use of energy data, as well as a code of conduct for interoperability, are to be created. IoT-enabled heat pumps can contribute to the following EU energy policy objectives: increasing participation in demand response programs for energy-efficient appliances and increasing the cyber security and resilience of the energy system.

5. Acknowledgement and outlook

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Annex 56 has shown that digitalization also plays an essential role for heat pumps. Therefore, a new Annex idea is being developed in the Heat Pumping Technologies TCP, focusing on the use of digital methods for heat pumps. Possible topics include product design and certification (e.g. digital twin for product life cycle, semantic modeling for generic description of heat pumps for modeling, modular heat pump for component replacement and design adaptation through simulation, hardware-in-the-loop testing for dynamic conditions, flexibility assessment and interactions), integration (AR-assisted set-up, data-based fault detection during installation), and data-based operational optimization (predictive maintenance, AR-assisted maintenance, model-based heat pump control).

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