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Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 50

Heat Pumps in Multi-Family Buildings for Space Heating and Domestic Hot Water

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 organized 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 optimize 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 organizations. 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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Foreword

It was never so clear. We must stop, or at least significantly reduce, the use of fossil fuels. The most important argument to do that is the mitigation of consequences of the climate change. The newest IPCC report [1] does not leave any illusion – the life on our planet as we known it and are used to, will no longer be possible. The consequences of "business as usual" would be dramatic.

The second reason to rethink the dependency on fossil fuels is the political one. Of course, strictly connected to the economy. The painful reliance on energy sources was never so visible as in days of the Russian invasion on Ukraine.

One of the ways how to achieve the transition to a net zero energy system by 2050, while ensuring stable and affordable energy supplies, is described in the IEA Roadmap "Net Zero by 2050" [2]. Among its key conclusions is that the half of the global heating demand must be covered by heat pumps in 2045. Several other studies also underline the importance of heat pumps. Comprehensive modelling study performed by the Cambridge Econometrics [3] show the climate, economic and social impacts for different scenarios: a large uptake of heat pumps (Electrification), green hydrogen use (Green Hydrogen), and a mix of both (Mixed), in individual heating systems and district heating networks. The results are very clear: the shift to electrified and highly efficient buildings will generate the largest socio-economic benefits for Europe.

Heat pump applications in multi-family buildings are still rather an exception. To reach the goals sketched in the mentioned roadmap, it must change to a standard. The strong intention of the Annex 50 group was to contribute to this challenging task.

Abstract

The present report documents the results of Annex 50 “Heat Pumps in Multi-Family Buildings for Space Heating and DHW”. The work started officially in 2017 and was planned for 4 years. Due to Covid-19 pandemic, combined with a longer absence of the operating agent in the initial year, the Annex has been extended until June 2021. The active Annex group consisted of seven countries (Austria, Denmark, France, Germany, Italy, Netherlands, and Switzerland).

The focus of the Annex 50 was on solutions for multi-family residential buildings, with the attempt to identify barriers for heat pumps in this field and how to overcome them. Upon the demand of the participating countries, new buildings and retrofit have been considered, together with buildings with a higher specific heating demand.

The working group has succeeded in elaborating a general classification of heat pumps solutions for multi-family residential buildings. They have been described in a standardized way according to eight representative categories. Overall, 13 solutions have been identified, ranging from a fully centralized system to a completely decentralized system (each-room solution). The solutions have been grouped into five “families”, each grouping specific sub-solutions.

Parallel to the theoretical classification of the solutions, numerous case studies representing implementation of heat pumps in multi-family buildings have been collected. The cases show a wide variety of possibilities for use of heat pumps, depending on the energetical standard of the building, its number of apartments, heat source and further characteristics. To reflect the holistic approach and to illustrate the practice, each case study is connected to a corresponding theoretical solution.

A multifunctional website has been designed and expended during the duration of the Annex, with the aim to disseminate its outcomes in an attractive and user-friendly way.

It is intended to continue the presented work, inter alia through extending the case studies database within the frame of the new Annex “Heat pumps for multi-family residential buildings in cities”.

Table of content

1. Executive Summary

The present report documents the results of Annex 50 “Heat Pumps in Multi-Family Buildings for Space Heating and DHW”. The work started officially in 2017 and was planned for 4 years. The active Annex group consisted of seven countries (Austria, Denmark, France, Germany, Italy, Netherlands, and Switzerland).

The focus of the Annex 50 was on solutions for multi-family residential buildings, with the attempt to identify barriers for heat pumps in this field and how to overcome them. Upon the demand of the participating countries, new buildings and retrofit have been considered, together with buildings with a higher specific heating demand.

Summary in one phrase: good examples exist, more standardization needed
The use of heat pump systems in apartment buildings is possible and already practiced, as shown by many examples from several countries. Nevertheless, there is still no evidence of a wider use of this solution for heat supply; the reasons being both of administrative and technical nature. This applies both to new, as well as to existing buildings.

Key Findings:

It is possible
The use of heat pump systems in apartment buildings is possible and already practiced, as shown by many examples from several countries. The variety of multi-family buildings and their characteristics make it possible to apply various technical solutions based on heat pumps.

More standardization needed
At the same time, this diversity leads to individual solutions which are difficult to apply on a large scale.

The challenge to apply heat pumps
There is still no evidence of a wider use of heat pumps in multi-family buildings for heat supply. The challenge to apply heat pump technologies and renewable energy in multi-family buildings is rather complex. Both administrative (e.g., property rights) and technical challenges stand in the way to a broad implementation of the technology.

The technical barriers to overcome

- *Heating capacity and supplied temperature*
  The multi-family buildings stock is quite old in all participating countries, with most buildings built before 1970. Without any refurbishment, these MFB need high heating temperatures (> 60°C). Moreover, in most countries, state-of-the-art heat pumps provide heating capacities below 100 kW. These types of products are only adapted for efficient buildings, not for collective heating production in old ones.
- *Access to the heat sources*
  Most of multi-family buildings are in cities, with high building density. Therefore, the access to a geothermal heat source is complicated. For air-source heat pumps the place of the outside unit (evaporator) is most challenging in respect of both – maximal capacity and the sound emission.

Key results from the Annex:

“Solution matrix”
The working group has succeeded in elaborating a general classification of heat pumps solutions for multi-family residential buildings. They have been described in a standardized way according to eight representative categories. Overall, 13 solutions have been identified, ranging from a fully centralized system to a completely decentralized system (each-room solution). The solutions have been

grouped into five “families”, each grouping specific sub-solutions.

Case studies database
Parallel to the theoretical classification of the solutions, numerous case studies representing implementation of heat pumps in multi-family buildings have been collected. The cases show a wide variety of possibilities for use of heat pumps, depending on the energetical standard of the building, its number of apartments, heat source and further characteristics. To reflect the holistic approach and to illustrate the practice, each case study is connected to a corresponding theoretical solution.

It is intended to continue the presented work, inter alia through extending the case studies database within the frame of the new Annex “Heat pumps for multi-family residential buildings in cities”.

2. Background

The building sector plays a significant role for the energy consumption in every country.

Besides electricity generation and the transport sector, it is the most important sector regarding the greenhouse gas emissions. Therefore, the massive reduction of CO_2 emissions from buildings and the long-term achievement of a climate-neutral building sector can be considered inseparable.

New domestic buildings are often constructed with a building envelope and heating system designed for low energy consumption and the potential to use new renewable energy technologies, such as heat pumps. For multi-family buildings, the challenge of applying heat pump technologies and renewable energy is more complex. The aspect of ownership varies among member countries of the IEA HPT Implementing agreement. While in some countries multi-family houses are often owned by local cities, communities, or housing corporations, in other countries ownership is private and divided into individual apartments. Even combinations of ownership by housing corporations and private owners in one building exist. This implies extra challenges at organizational, financial and implementation level.

Multi-family houses bring along a range of heat demand characteristics. First, the share of domestic hot water demand in the total heat demand varies due to varying building standards as well as different climate zones. Second, the temperature level of the heating system is influenced by these aspects as well as by the installed heating transfer system. Henceforth, dealing with the variety of heat demand characteristic bears the challenge on the way to a broader spread of heat pumps in multi-family buildings.

Annex 50 was covering a comprehensive range of topics that relate exclusively to multi-family buildings. Within this Annex, the variety of key aspects for usage of heat pumps in multi-family buildings have been considered. The outcome of the Annex allows to understand better the technical and non-technical barriers, presents in a comprehensive way different theoretical solutions of heat pumps implementation in multi-family buildings as well as visualises a numerous case studies showing the practical implementation.

3. Introduction

The perception of heat pumps by the policy- and lawmakers has changed significantly in favour of heat pumps as a solution for the decarbonisation of heating in the housing sector. New strategies to reach climate neutrality point to heat pumps as the key solution.

Most heat pumps installed in Europe are dedicated for single family houses. To reach the goals mentioned in the previous paragraph, heat pumps must be installed also in multi-family buildings. The analyses completed within the Task 1 of the Annex 50 show clearly that one of the major barriers of a broader application of heat pumps in multi-family buildings is a lack of knowledge. Both on the side of owners of the buildings or apartments, as well as investors.

The diversity of the multi-family buildings is significantly higher than in the case of single-family buildings. This results in more numerous and complex solutions which can be implemented for covering the heating demand and domestic hot water needs. Consequently, the choice of the most appropriate solution is a much more difficult task.

To overcome this problem, the Annex 50 group proposed the simplified categorisation of possible heat pumps implementation variants in multi-family buildings. The resulting "solution matrix" described in this report is one of the major achievements of the Annex 50.

Second result worth highlighting is the data base of case studies with examples of heat pumps implementation in multi-family buildings in several European countries.

Described results are available not only in form of the present report but also on a dedicated website of the Annex. Both, the "solution matrix", as well as the "case studies database" are presented in an attractive way on the interactive website https://heatpumpingtechnologies.org/annex50/. This website has to be considered as an integral part of the final report of the Annex 50.

2. Holistic approach to present the results of Annex 50

The approach of the Annex 50 was to find the way to create a holistic (integrated) method of presenting its results, as well as to work on all Tasks simultaneously. The result of this approach is a “solutions matrix”. Each part of the matrix can be used or presented as a standing alone component and is connected to a specific Task of the Annex.

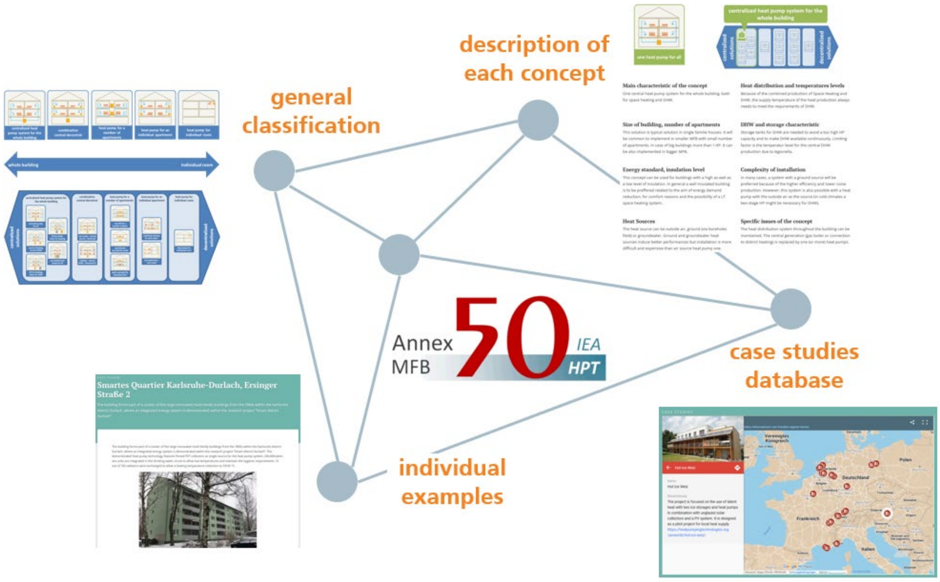


Figure 1: Main elements of the "solutions matrix", the holistic result of the Annex 50

The first part of the Task 1 consists of the country reports from all participating countries. The second part builds an overview of various heat pump solutions in MFB. The broad scope of possibilities, combined with numerous types of multi-family buildings showed the need for a categorization system, which would allow for a simplified but systematic way of structuring the information gathered. As a result, five “solutions” families have been identified, reaching from a fully centralized system to a completely decentralized system (each-room solution). Most of the “families” consisted of several “family members”, which are sub-solutions of the general categorization. All together 13 general solutions have been identified.

The next step, and at the same time the main work within the Task 3, was a deeper analysis and description of each solution. This part took place with a significant time-investment of each Annex partner. Several discussions about this topic took place, not only between the Annex partners but also during national workshops organized specifically for this purpose.

The work within the Task 4 (demonstration and monitoring) resulted in the collection of case studies representing implementation of heat pumps in multi-family buildings. Case studies collected in countries participating in the Annex 50 show a wide variety of possibilities with heat pumps. The cases varied as to the energetical standard of the building, its number of apartments, heat source of the heat pump and further characteristic. To fulfil the holistic approach and to illustrate the practice, each case study is connected to the corresponding theoretical example described in the Task 3.

It is the sincere belief of the work group, that this innovative way of reporting will help disseminate the outcomes from the Annex 50 in an attractive and user-friendly way. The central achievement connected to Task 5 is the multifunctional website of the project (described in the section 3 Website).

The results achieved within the Task 2 (simulations and modelling) are standing alone and are not a part of holistic approach of results. The summary of the Task 2 has been described in the chapter 5. The results of Task 2 delivered by countries involved in simulative or/and modelling work are available on the website of the Annex50.

3. Summary of Task 1

In Europe, the market for heat pumps (HPs) in residential buildings has grown steadily for several years in most countries. However, this global figure hides very different situations depending on the type of buildings. Whereas in new individual houses HPs are the most spread solution, their market in multi-family buildings (MFB) remains low, in new buildings as well as in existing ones.

The first task of Annex 50 was to collect and analyse data from the eight participating countries in order to identify particular and common characteristics of buildings, technical aspects and legal regulations that explain the situation of heat pumps in MFB, as well as to identify particular and common barriers to the development of HPs in MFB that are essential to overcome.

3.1. Introduction: Place of heat pumps in European Buildings

In all participating countries, residential heat pumps increase their annual sales over the last decade, in particular since 2014. This overall dynamic of sales growth can be seen in terms of residential market penetration (see Figure 1). We can thus observe a pronounced dynamic, with sometimes still modest heat pump penetration rates despite booming sales, but a clear and increasingly rapid progression. However, this global development hides very different situations depending on the types of residential buildings.

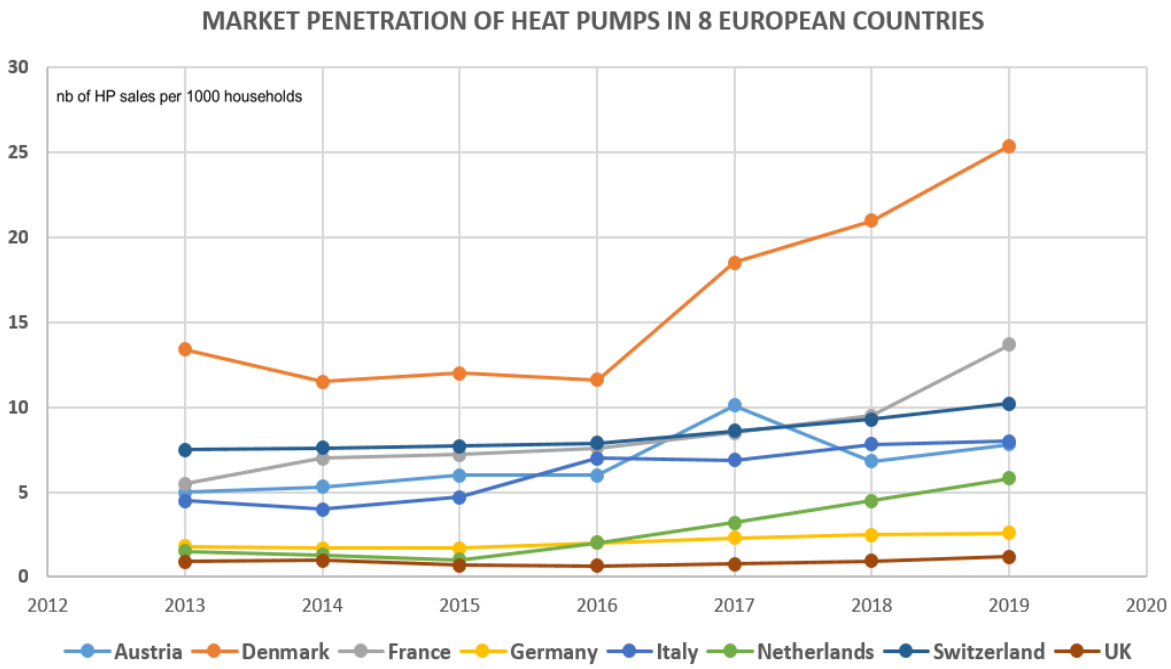


Figure 2: Residential market penetration in the 8 participating countries (source EHPA www.stats.ehpa.org)

In fact, heat pumps still represent a small part of heating systems in the global buildings stock in all participating countries, ranging from a few percent to 10% (excluding Denmark). Except for some countries like Austria, Switzerland or France where there are significant differences between HPs shares in MFB (1 to 7%) and individual houses (10-15%), differences in the spreading of HPs depending on the building types are not very significant when considering stocks.

However, the differences in the market development of heat pumps between individual houses and MFB are more obvious for new buildings. In some countries, such as Austria, France and Germany, heat pumps are the first heating system in new built individual houses, with a share of about 50% or more. However, their share increases rapidly in new built MFB in all countries. Looking at the three countries mentioned above, heat pumps account for only 4-5% of heating systems in new collective housing in France, but more than 20% in Germany and Austria.

3.2. The driver: policy framework

All participants represent European countries. Except for Switzerland, the political background is the same and the main relevant directives concern the energy performance of buildings, energy efficiency and performance requirements for energy-related products. Moreover, these countries are affected by the 2020 and 2030 targets for CO2 emission reduction, energy efficiency, and improving the use of renewable energy.

To address these objectives, each participating country has developed a specific regulatory system to encourage renewables and reduce energy consumption in the building sector.

Among the regulations that have gone into effect in each country, two types of rules are particularly important for the heating systems market: Building codes for newly constructed buildings and incentive programs for existing ones.
Most countries have adopted building regulations based on maximal consumption. The maximum consumption value and the uses included in the calculation vary from country to country. Some regulations add a performance requirement on the building structure to minimize the energy needs. This is a stated way to share the effort between building structure and system efficiency to reduce energy consumption. In others, the energy consumption requirement is so stringent that efforts must be made to address both aspects, even if there is no building structure efficiency requirement. It should be noted that France is the only country where the requirements for collective houses are different and less severe than for individual houses.

In addition, several countries have planned or already implemented a ban on fossil fuels, including natural gas, in newly constructed buildings (Denmark in 2013, Netherlands in 2018, France in 2021 and UK announced for 2025). Without being so radical in their stated desire to eliminate fossil fuels, the regulations of other countries are however sufficiently restrictive in terms of energy consumption for heating and domestic hot water uses to promote the development of efficient systems such as heat pumps.

Incentives schemes can have various logic depending on the country: Promotion of efficient technologies for all markets, contribution of large energy consumers to energy efficiency measures (energy savings or energy efficiency certificates), incentive for renovation of existing buildings and facilities with a wide range of supported technologies, special programs to replace fossil fuel boilers in existing buildings, etc. Regardless of the logic of the incentives, the installation of heat pumps is included in the system and even becomes a central part of it. In all countries, heat pumps are promoted through grants, tax credit or reduction.

The conclusion is that the policy framework, with more and more restrictions, favours more and more the development of heat pumps in buildings. The few differences in regulations are not enough to explain the lower development of heat pumps in collective housing compared to single-family homes. Thus, to achieve a sustainable development of heat pumps in MFB, more obstacles than the legal regulations must be overcome.

3.3. The barriers to overcome

Technical barriers

- Heating capacity and supplied temperature
  The multi-family buildings stock is quite old in all participating countries, with an average share of 52-60% of buildings built before 1970. The majority of MFB stock was built before the first building regulations. For these MFB (<1970), the heating demand represent 120-150 kWh/m2.an. Without any refurbishment, these MFB need high heating temperatures

(> 60°C), not easily suitable for heat pump application.
Moreover, in most countries, state-of-the-art heat pumps provide heating capacities below 50 kW. These types of products are only adapted for efficient buildings, not for collective heating production in old ones.

- Access to the heat sources
  Most of multi-family buildings are located in cities, with a more or less high density of building development. Therefore, access to a geothermal heat source, is complicated. For air-source heat pumps, the collective heat source is often the only solution to avoid multiple and visible outdoor units, that can be architecturally difficult to integrate or even prohibited. In the collective case, the unique outdoor unit must be installed on the roof, which implies a terrace roof, or on an outside car parking lot or garden near the technical room.

Economic Barriers

- Capital costs
  For this type of building, the high capital costs affect the competitive position of heat pumps compared to fossil boilers or direct electric heating. This criterion is particularly significant in new built operations, which are often (75% of total cases) managed by private investors. The main focus of this key type of market operator is on the prime cost of the apartments and consequently on their selling price. Indeed, for each new construction project, the investor estimates a maximum sale price that corresponds to the type of apartment, the location of the project, etc. As a result, renewable heating systems are currently rare. As investors are rarely able to evaluate the heating provided by heat pumps in their buildings, this rather expensive heating system has a direct impact on the cost price without affecting the sales price. At the moment, building owners and investors are not yet convinced.

- Energy prices (state 2019)
  The actual prices for oil and natural gas as well biomass have a high influence on the heat pump market. As the prices of crude oil and other fossil energy sources have fallen in recent years and remained stable at low levels, there is a significant barrier to investment in new heating technologies that use electricity; its price varies greatly from one participating country to another but is always high compared to the price of gas. The ratio between electricity and gas prices ranges from 1.7 to 4. If an average efficiency (SPF) around 3 is considered, in few countries (Denmark, Germany, UK), this SPF doesn't compensate the energy prices ratio. This means that even the operating costs can for a heat pump system can be higher than for a gas boiler system.

3.4. Conclusion

In the 8 European countries participating in Annex 50, heat pumps are well established in single family homes, but are still struggling to gain acceptance in collective housing, despite the regulatory environment being increasingly favourable to their installation in all countries. Common barriers can be technical (access to the heat source, capacity of available products) or economic (investment cost, energy prices). An essential point common to all countries: the lack of knowledge. The heat pump is still too often considered as a product only dedicated to the individual house. Significant demonstration work is needed.

4. Summary of Task 2

The performance of heat pumps must be compared to other options, like gas-boilers, in order to evaluate both technically and economically. In Task 2 an analysis of available modelling tools was performed, with the goal of identifying the optimal balance between the needs of simple and quick tools and the complexity of the system-building-users-weather interplay. The main challenge considered was to validate the minimum required set of tools needed to assess the technical-economic feasibility of the installation of a heat pump system in a residential building. To this extent, a collection of experiences from the partner countries was considered.

4.1. The modelling challenges

The list of available models is a catalogue of different approaches, that inevitably simplify one or another of the complexities at the building energy system level:

- The energy demand is a function of the user behaviours and weather. Both can be modelled only by a statistical/probabilistic approach.
- The building thermal dynamic is strongly influenced by thermal capacity, and a complex multi-zone transient approach is often need.
- The real ventilation flow rate in naturally ventilated building is hard to predict.
- The actual indoor temperature is often significantly different among the rooms and flats in a building if precise control systems are not installed.
- The efficiency of a heat pump is a strong function of the system supply temperature, which is, in turn, a function of the previously explained variable parameters and of the specific system design.
- The final environmental and economic costs of a typical electricity driven heat pump is a function of the country or regional or district electrical system and network, which can also be related to the thermal network if co-generative assets are installed.

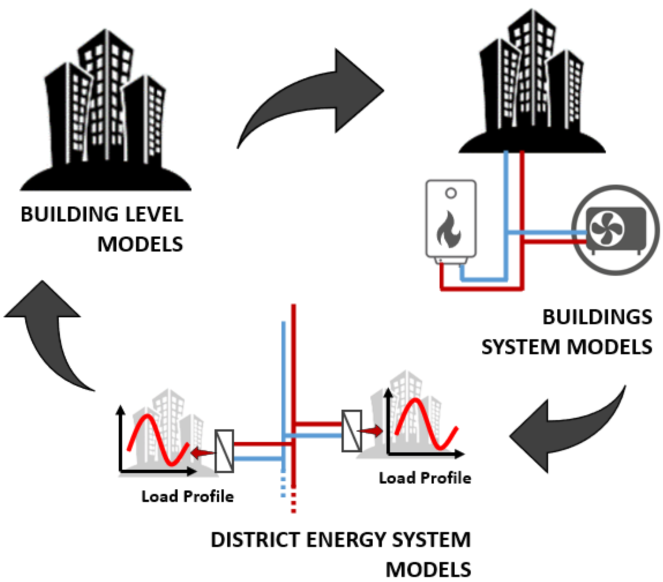


Figure 3: The complex interplay between different scales of modelling of the building energy consumptions

4.2. Partners experiences

The partners shared experiences in modelling. Some of them have been

validated against measurement of real energy consumptions.
As a sample of the list of building level models, the following table is presented:

Software or Programming Language	Transient / Steady-State simulations	Time Step	Geometry	Open: - Real Input Data - Modification the Model	Interaction with the other levels	Main Input	Main Output
EnergyPlus	Steady-State	min	3D PlugIn	Open	FMU	geometry, physical parameters, schedules, weather, etc	temperatures, energy balances, etc.
Trnsys	Steady-State	min	3D PlugIn	Open	FMU	geometry, physical parameters, schedules, weather, etc	temperatures, energy balances, etc.
EnergyPlus	Transient	1 minute to 1 hour	1 to 100 zones	Open	FMU	geometry, physical parameters, schedules, weather, etc	temperatures, energy balances, etc.
Trnsys	Transient	1 minute to 1 hour	1 to 40 zones	Open	FMU	geometry, physical parameters, schedules, weather, etc	temperatures, energy balances, etc.
IDA ICE	Transient	adaptive	1 to 100 zones	Half open (possibility to upload real schedules, but no FMI)		geometry, physical parameters, schedules, weather, etc	temperatures, energy balances, etc.

And as a sample of building system level model lists, the following table can be considered.

Software or Programming Language	Transient / Steady-state simulations	Time Step	Geometry	Open: - Real Input Data - Modification the Model	Interaction with the other levels	Main Input	Main Output	Additional Description
Dymola/Modelica	Transient	Automatic	1D	open	FMU	geometry, component characteristics (e.g. isentropic efficiciency of compressor), material/fluid data, fluid inlet conditions	fluid outlet conditions, heating/cooling capacities, electrical power consumption	models can be exported as FMU --> so the sky is the limit in terms of interaction with other system levels
EnergyPlus	Steady-State	min	3D PlugIn	Open	FMU	geometry, physical parameters, schedules, weather, information about HVAC componentes	temperatures, energy balances, etc.	models can be exported as FMU --> so the sky is the limit in terms of interaction with other system levels
Trnsys	Steady-State	min	3D PlugIn	Open	FMU	geometry, physical parameters, schedules, weather, information about HVAC componentes	temperatures, energy balances, etc.	
EnergyPlus	Mostly Steady-State, transient for some components (water tanks, pipes)	1 minute to 1 hour	1 to 100 zones	Open	FMU	component information, loops of components, control elements	energy balances, temperatures, flow rates	
Trnsys	Mostly Steady-State, transient for some components (water tanks, pipes)	1 minute to 1 hour	1 to 40 zones	Open	FMU	component information, component connections...	energy balances, temperatures, flow rates	
IDA ICE	Steady-State for some components, transient for some components	adaptive	1 to 100 zones	Half open (possibility to upload real schedules, but no FMI)		component information, component connections, als...	energy balances, temperatures, flow rates	

4.3. Simplified front-end engineering tool

A simplified approach for front-end engineering or technical-economical feasibility studies is presented, in which a linear and steady state model of outdoor temperature-energy demand is considered and a steady state relation of COP of heat pump as a function of supply and outdoor temperatures is applied.

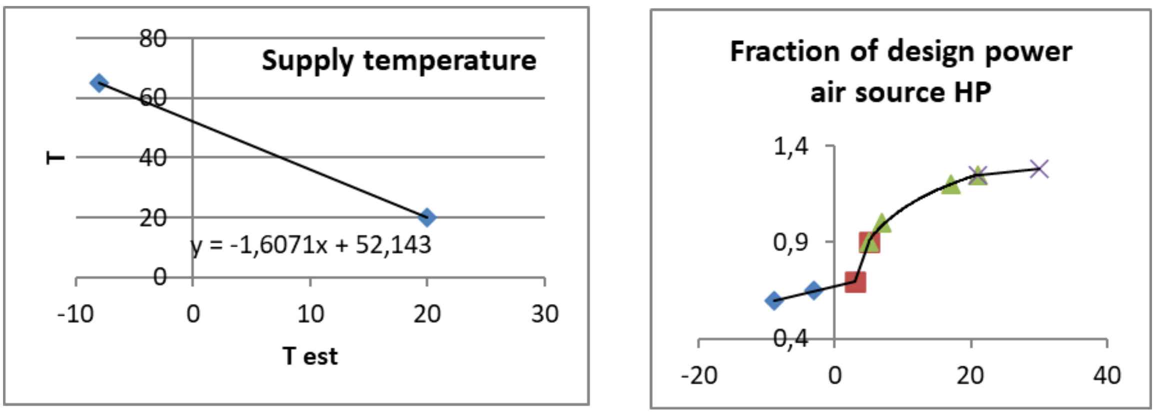


Figure 4: Linear correlation for supply temperature and simplified steady state COP curve

5. Summary of Task 3 – "Solution Matrix"

During the process of gathering knowledge and practice for Task 3, the work group faced a rich variety of cases and characteristics to consider. Depending on the focus of the system design, e.g., a specific MFB type, the conclusions would vary. Structuring the information in a matrix format provided a response to this issue. The work was carried out with the vision of a description of all solutions in a standardized way. This allowed to explore each scenario, from centralized to completely decentralized HP installation, through the lens of new to non-renovated MFB, building size, heating and/or domestic hot water (DHW) production need, HP only or hybrid system and to reflect on specific issue for each one. It is an attempt to cover all potentially encountered cases. The intention is to help identify the best possible solution for each case and inform on concepts that may be unusual in some countries.

The graphical keys to understand the conceptual schemes are given in the illustration below (Figure 5).

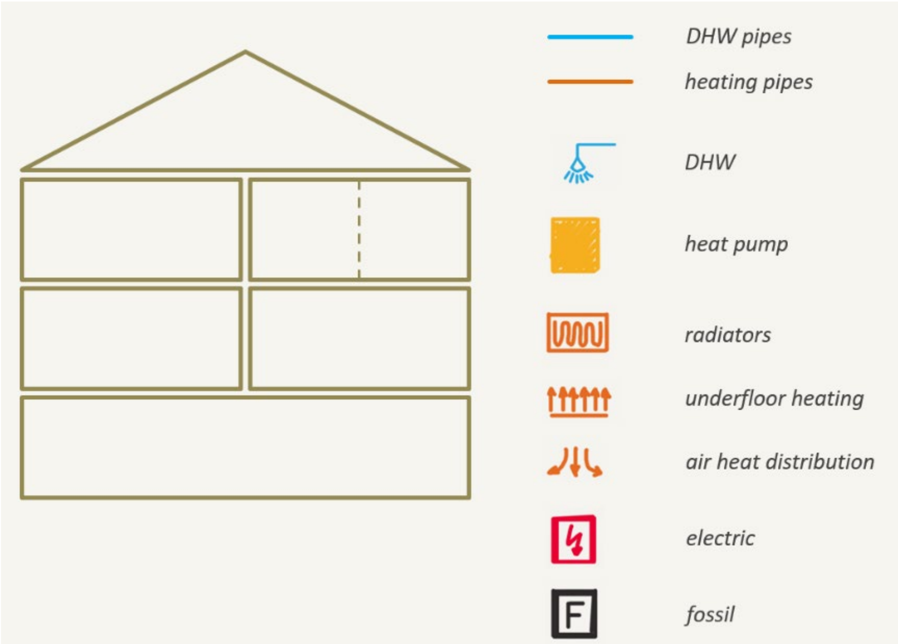


Figure 5: Graphical keys to schematic representation of solutions

The two modes, heating and domestic hot water production, are represented by pipes of different colour. The heat emitter for heating mode can be underfloor, radiators or a mix of them. The illustration is given as an example. Electric or fossil heat productions are assumed in some solutions as a heat production complement or as the main heat producer for one mode or another. If only one mode is represented, it means that the other is taken care of otherwise with a solution that is not linked to the HP. Solutions can be centralized for the whole building or several apartments, a mix of central-decentral, and individual by apartment or even by room (dotted line subdivision in apartment box).

5.1. General classification

A key point to classify heat pump systems, is to define the level at which the integration is realized. This ranges from all centralized to completely decentralized installations with different types of intermediate solutions. This first level of classification consists of five so-called “solutions families”. These generic groups are represented aligned in the following schematic drawings ranged by their level of system centralization (Figure 4).

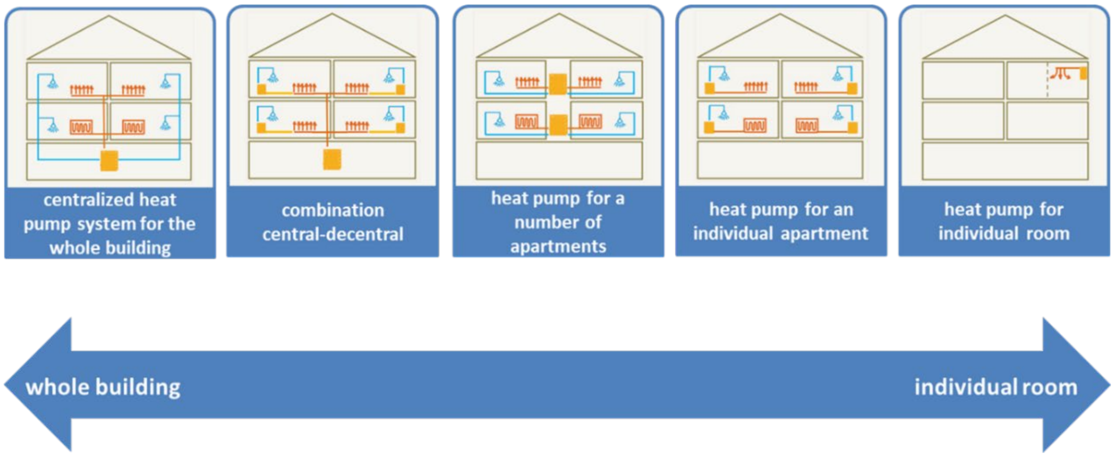


Figure 6: Solution families

Each “solution family” comprises several “family members”. The members are variations within one logical group.

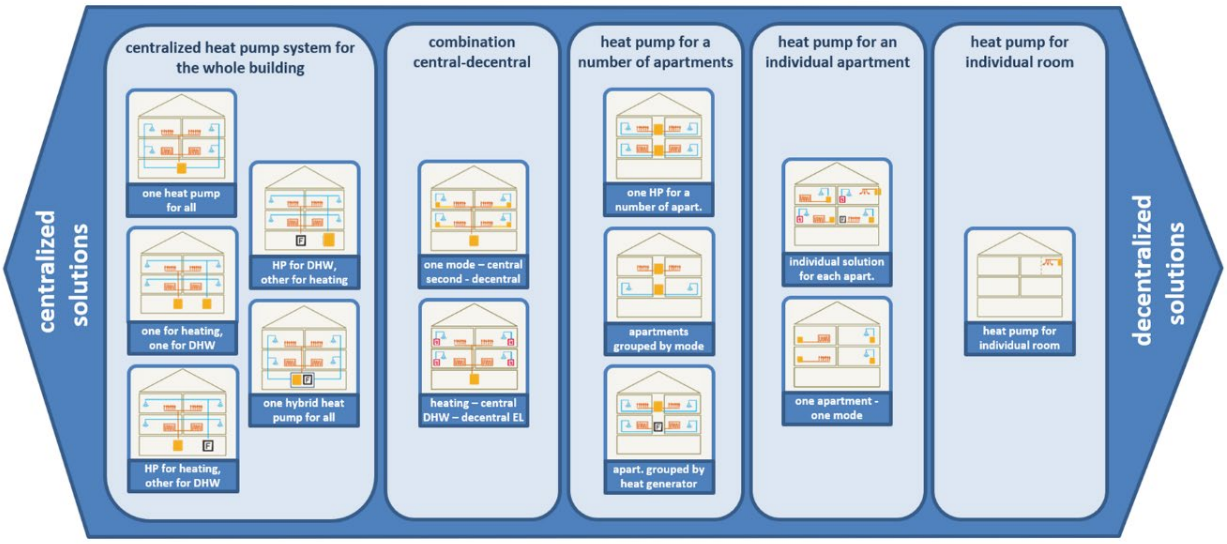
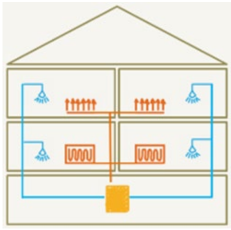
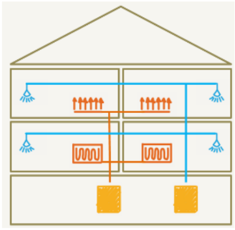


Figure 7: The overview of the 13 resulting solutions identified is shown in the Figure 3 sorted by families according to their degree of system centralization

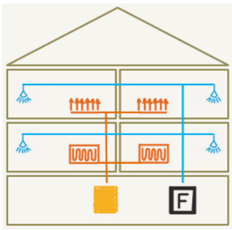
The following listed solutions have been identified. They are described in order from the most centralized to the most decentralized concept.



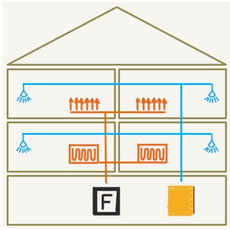
Solution 1.1 „one heat pump for all“
One central heat pump system for the whole building, both for space heating and DHW.



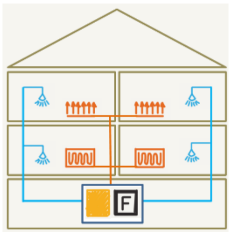
Solution 1.2 „one for heating, one for DHW “
One heat pump system for each mode. One for space heating, separate one for DHW.



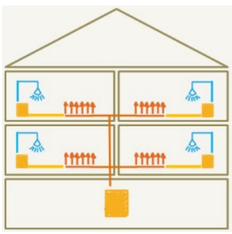
Solution 1.3 „ HP for heating, other device for DHW “
One heat pump system for the space heating, separate heat generator (fossil, biomass, electric, …) for DHW.



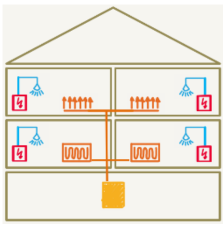
Solution 1.4 „HP for DHW, other device for heating “
One HP system for DHW, separate heat generator (fossil, biomass, electric, …) for space heating.



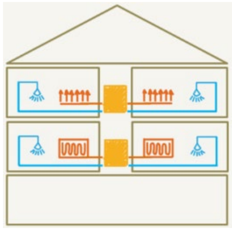
Solution 1.5 „one hybrid heat pump for all “
One hybrid heat pump system for space heating and DHW for the whole building



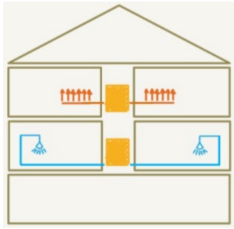
Solution 2.1 „ one mode – central, second - decentral “
One central heat pump system for one mode (for example space heating). Decentral heat pumps for the second mode (for example DHW).



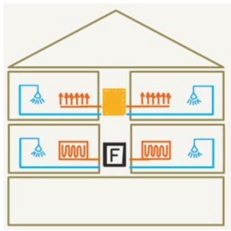
Solution 2.2 „ heating – central, DHW – decentral EL “
One central heat pump system for space heating. Decentral direct electrical heaters for DHW.



Solution 3.1 „one HP for a number of apartments “
One heat pump system for space heating and DHW for several apartments (usually grouped by levels or staircases).

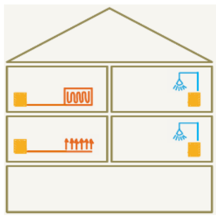


Solution 3.2 „apartments grouped by mode “
One heat pump system provides one mode (space heating or DHW) for several apartments (usually grouped by levels or staircases).



Solution 3.3 „ apartments grouped by heat generator “
The apartments are grouped by heat generators (usually grouped by levels or staircases).

Solution 4.1 „ individual solution for each apartment “
Each apartment has individual concept of space heating and DHW.



Solution 4.2 „ one apartment - one mode “
Decentral heat pump for one mode for one apartment.

Solution 5.1 „ heat pump for individual room “
One heat pump for space heating (or cooling) for one room of the apartment.

5.2. Solutions description

The factsheets following on next pages include the description of all 13 general solutions. Each one is described in detail within 8 categories:

1 Main characteristic of the concept
Maximally concise description of the solution

2 Size of building, number of apartments
This category indicates for what size of the building the solution is favourable. For the sake of clarity, three categories of the buildings have been defined. Depending on the number of apartments: “small” buildings consist of 4 to 10 apartments, “average” - 11 to 20 apartments, and “large” – of more than 20 apartments

3 Energy standard, insulation level
In this category three building types have been distinct. New buildings with a high energetical standard; retrofitted with an average energetical standard and old, un-retrofitted buildings with a poor energetical standard. It was decided not to declare strict values expressing the energy demand.

4 Heat Sources
The general categorization of the solutions in the “solution matrix” does not consider the heat source of the building. This description category is an attempt to indicate which heat sources are preferable for each solution.

5 Heat distribution and temperatures levels
This category describes the type and way of heat distribution for space heating and DHW. Additionally, the temperature levels for each mode are indicated.

6 DHW and storage characteristic
This category describes the type and way of provision of the DHW for the building. Also, the necessity of the storage tanks is indicated.

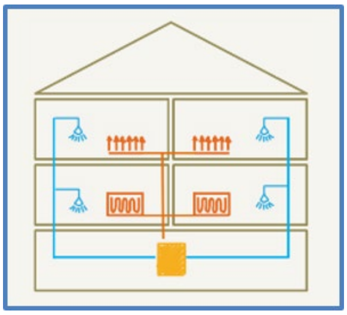
7 Complexity of installation
The estimated effort for the installation of the system is described in this section.

8 Specific issues of the concept
Any additional information about the solution finds its place under this category.

General remarks

1. Presented descriptions do not aim at being fully exhaustive. They rather form a basis for further discussions.
2. Presented description of each category is deliberately short and simplified, so as to be understandable for broad audience. This approach consequences with technical superficiality.
3. Each description is a compromise between different views of the involved Annex partners. In some cases, a specific national perspective results in a different view on the topic.
4. Some descriptions within solutions from the same “family” repeat.
5. Some remarks are valid for all solutions and have a more general character. Amongst others:
    a. ground and groundwater heat sources induce better performances and can deliver free cooling, but installation is more difficult and expensive than for air source heat pumps.
    b. all solutions including the fossil heat generators must be avoided under the consideration of the long-term decarbonisation goals.
    c. during retrofitting, exchange of some or all radiators may be necessary (and is recommended) to lower the heating temperature.

1.1 One heat pump for all



Main characteristic of the concept
One central heat pump system for the whole building, both for space heating and DHW.

Heat distribution and temperatures levels
The heat distribution occurs through the whole building, which increases the heat losses. The heat pump must be able to provide two temperature levels for space heating and DHW or the heat production needs to always meet the high temperature requirements for DHW.

Size of building, number of apartments
This solution is a typical solution in SFH. It may also be common to apply in smaller MFB with a small number of apartments. In case of large buildings, more than 1 heat pump may be necessary to meet the required heating capacity (cascade solution).

DHW and storage characteristic
In the central solution for DHW the heat losses account for a significant part of the energy consumption. Storage tanks for DHW are needed. Separate consideration about legionella needed (for example ultra-filtration).

Energy standard, insulation level
Most suitable for buildings with higher energy standards (new buildings). This concept may be used also for buildings with an average energy standard. For poor insulated houses it is not excluded but more challenging to implement.

Complexity of installation
In case of retrofitting, the old heating distribution system may be maintained. In some cases, partial or complete exchange of radiators in each apartment may be required. In case of new buildings, long piping through the whole building is necessary.

Heat Sources
All heat sources possible. For large buildings with high energy demand the heating capacity can be a restricting factor for the outside air as a heat source. When outside air is used as HP-source, the HPs should preferably be installed on the roof or in dedicated containers near technical room.
For larger systems, the sound emissions may be a problem for air-source heat pumps

Specific issues of the concept
The old heat generator can be replaced (during retrofitting) without changing the distribution system.

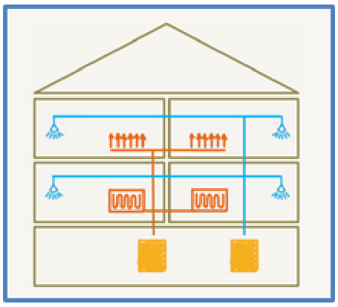
Positive aspects

- Good for smaller MFB’s
- One controller
- Existing distribution maintained
- Simple replacement of a gas boiler

Negative aspects

- High distribution losses

1.2 One for heating, one for DHW



Main characteristic of the concept
One heat pump system for each mode. One for space heating, separate one for DHW.

Heat distribution and temperatures levels
Because of the separate production of space heating and DHW and, consequently, different supply temperature levels, each heat pump may be optimized for own purpose. It includes, for example, the capacity of the heat pump and the refrigerant.

Size of building, number of apartments
This solution is suitable for all sizes of buildings, but often used for larger buildings.

DHW and storage characteristic
Storage tanks for DHW are needed. Heat pump must meet high temperature requirements of the DHW. Central distribution of DHW results in high distribution energy losses.
Separate consideration about legionella needed (for example ultra-filtration).

Energy standard, insulation level
This concept can be used for buildings with a high, as well as a low level of insulation. In new buildings two temperature levels are possible, which allows to optimise each heat pump for certain temperature level.
Using two different heat pumps allows implementation of different refrigerants.

Complexity of installation
In case of retrofitting, the old heating distribution system can be maintained. In some cases, partial or complete exchange of radiators in each apartment may be required. In case of new buildings, long piping through the whole building is necessary.

Heat Sources
All heat sources possible. Using two different heat pumps allows also for using two different heat sources. For large buildings with high energy demand the heating capacity may be a limitation factor for outside air as a heat source. When outside air is used as HP-source, the HPs preferably should be installed on the roof.
For larger systems the sound emissions may be a problem for air source heat pumps.

Specific issues of the concept
The old heat generators may be replaced (during retrofitting) without changing the distribution system.
Specific heat pumps for each mode may be beneficial in terms of lower capacity needed, used refrigerants, chosen heat sources, etc.).

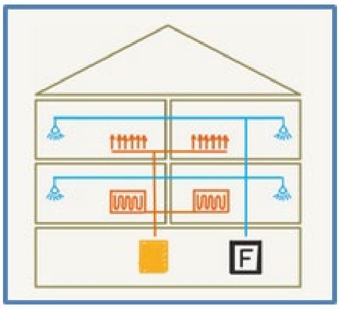
Positive aspects

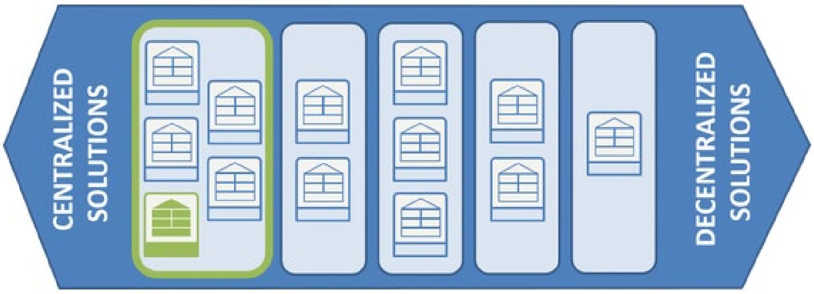
- Good for larger MFB's
- Splitting functions may lead to higher efficiencies

Negative aspects

- High distribution losses

1.3 Heat pump for heating, another device for DHW





Main characteristic of the concept
One heat pump system for the space heating, separate heat generator (fossil, biomass, electric, …) for DHW.

Heat distribution and temperatures levels
Separate production of space heating and DHW. The heat pump providing exclusively space heating may be optimized for this purpose. In case of an underfloor heating system, temperature required is significantly lower than for DHW.

Size of building, number of apartments
For all sizes of buildings, but often used for bigger buildings. For smaller and average buildings there is less need for bivalent systems.

DHW and storage characteristic
Fossil or biomass heat generator can easily provide high DHW temperatures, avoiding the problem of legionella.
Storage tank is recommended to provide reliability of the system and to allow for a more stable operation of the fossil generator.

Energy standard, insulation level
More applicable for older, not refurbished buildings with a higher heating energy demand.
This solution is generally not to be recommend for new buildings due to the use of fossil energy sources.
It can be a practicable solution if the investor wishes to exchange only one of the existing heat generators.

Complexity of installation
In case of retrofitting, exchanging only one mode may reduce the complexity of the planned construction work.

Heat Sources
All heat sources possible. The possibility to cover only heating demand with the heat pump, without the DHW, may be beneficial if the heat source for the heat pump is limited.

Specific issues of the concept
In case of retrofitting, this solution allows for exchange of only one heat generator towards to complete “heat pump only” solution in the second time step.

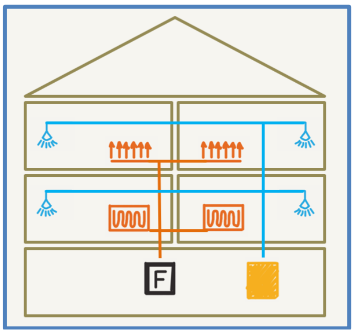
Positive aspects

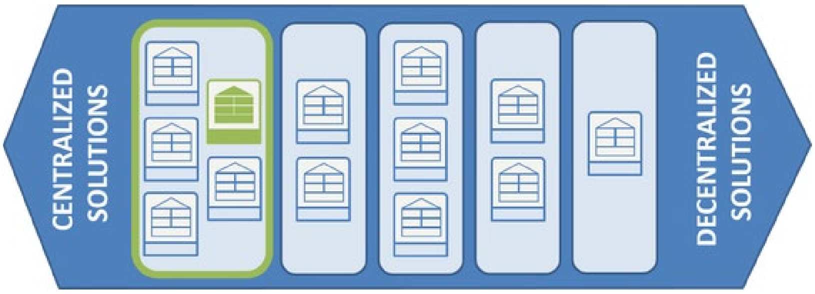
- Interim solution for larger MFB’s in a phased approach
- Easy legionella prevention

Negative aspects

- High distribution losses
- Partial use of fossil fuel

1.4 Heat pump for DHW, other device for heating





Main characteristic of the concept
One heat pump system for DHW, separate heat generator (fossil, biomass, electric, …) for space heating.

Heat distribution and temperatures levels
Separate production of space heating and DHW. Temperature level of the space heating system is not relevant for the heat pump.

Size of building, number of apartments
This solution is suitable for all sizes of buildings with the preference for smaller ones. Using specific heat source or refrigerant (for example CO_2) may be an indicator to select this solution.

DHW and storage characteristic
Heat pump provides DHW only. Consequently, appropriate high temperature level is necessary. Storage tanks are necessary for providing of DHW by the heat pump. In cold climates a two-stage HP might be necessary.

Energy standard, insulation level
This solution is generally not to be recommended for new buildings due to use of fossil energy sources.
Using a heat pump for DHW can only be practicable by retrofitting if existing system consists of two heat generators and the investor wants to exchange only one.

Complexity of installation
In case of retrofitting, exchanging one mode at a time may reduce the complexity of the planned construction work.

Heat Sources
All heat sources generally possible. For this solution some less frequently used heat sources like exhaust air or unglazed solar collectors can be used.

Specific issues of the concept
In case of retrofitting this solution allows exchange of only one heat generator and adopt a complete "heat pump only" solution at a second step.

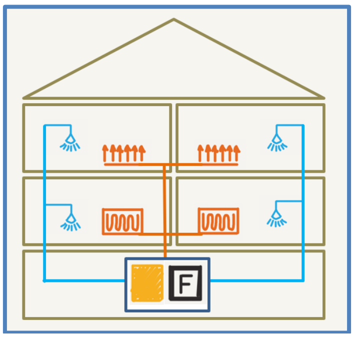
Positive aspects

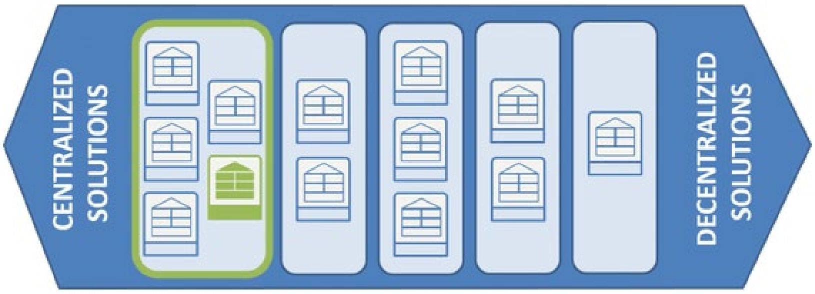
- Option for large and old MFB with no possibility for reduction of heating demand

Negative aspects

- High distribution losses
- Partial use of fossil fuel

1.5 One hybrid heat pump for all





Main characteristic of the concept
One hybrid heat pump system for space heating and DHW for the whole building.

Size of building, number of apartments
This solution is suitable for all sizes of buildings with the preference for larger buildings. Hybrid solutions may be useful if the installation of a heat pump with a large capacity is not possible. The limitation factors may be such as an insufficient heat source, particularly high supply temperature or a limitation of grid connection. In some cases, this solution allows for installation of a smaller heat pump as an add-on for existing boiler.

Energy standard, insulation level
This concept can be used for buildings with a high, as well as a low level of insulation. More applicable for older, not refurbished buildings with a higher heating energy demand.
This solution is generally not to be recommend for new buildings due to use of fossil energy sources.

Heat Sources
Hybrid heat pumps use commonly outside air as a heat source. Generally, all heat sources are possible.

Heat distribution and temperatures levels
Hybrid systems have several possibilities of separating space heating and DHW production. In most cases the heat pump delivers space heating during spring and autumn and will be assisted by the boiler during low outside temperatures in the winter. The better the insulation, the higher the contribution of the heat pump to the space heating demand.

DHW and storage characteristic
DHW can be pre-heated by the heat pump and finally heated to the desired temperature by the fossil part of the unit. This solution allows for an easier solving of the legionella issue.

Complexity of installation
In case of an add-on heat pump, the existing system (boiler) and the added heat pump must be connected and controlled together. The technical room must be large enough to install the heat pump and a storage tank close to the existing boiler.

Specific issues of the concept
The old heat generators may be replaced during retrofitting without changing the distribution system. The global performance of the system is aligned with the share of heat produced by the heat pump. Easy avoiding of legionella through achievement high DHW temperatures with the use of a fossil boiler.

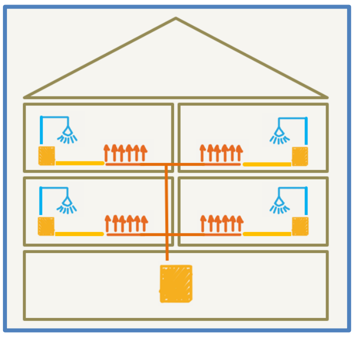
Positive aspects

- Smaller heat pump capacity
- Flexible: meets every grade of insulation
- Easy Legionella prevention

Negative aspects

- High distribution losses
- Partial use of fossil fuel

2.1 One mode – central, second - decentral



Main characteristic of the concept
One central heat pump system for one mode (for example space heating) and decentral heat pumps for the second mode (for example DHW). Also possible with a central heat pump if lower temperature level available or decentral heat pumps for a higher temperature level.

Heat distribution and temperatures levels
In this solution the higher temperature level for the DHW is provided by an additional (small capacity) heat pumps in each apartment. The central heat pump for the space heating (or for delivering the heat source for decentral heat pumps) can be optimized for lover temperature levels.

Size of building, number of apartments
This solution is suitable for all sizes of buildings with the preference for average and larger ones.

DHW and storage characteristic
DHW is produced separately in each apartment with a decentral heat pump. The heat distribution losses are significantly smaller than in case of a central solution. The size of DHW storages can by reduced. This solution allows an easier solution for the legionella issue.

Energy standard, insulation level
Depending on the final realisation of this solution, this concept can be used for buildings with any energy standard. The solution with a low temperature level for the heating and booster heat pumps for DHW is rather for buildings with a high energetical standard.

Complexity of installation
Rather a complex solution, which requires higher number of heat pumps. Possibility for a convenient usage of outside air as a main source of the central heat pump using roof top heat exchangers (evaporators).

Heat Sources
For the main heat pump, all types of heat sources are possible. For the decentral heat pumps - exhaust air or the or the return water pipe of the space heating may be the heat source.

Specific issues of the concept
May be convenient as a solution for high-rise buildings. Using different temperature levels. Boosting of temperature possible.

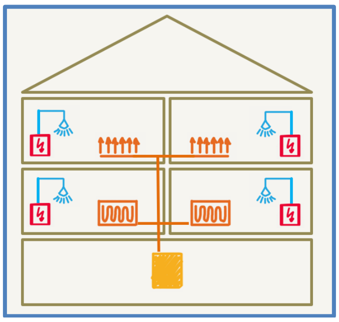
Positive aspects

- Individual DHW
- High efficiency possible
- Smaller distribution losses

Negative aspects

- Higher investment

2.2 Heating – central, DHW – decentral direct electric



Main characteristic of the concept
One central heat pump system for space heating. Decentral direct electrical heaters for DHW.

Heat distribution and temperatures levels
The heat pump providing only space heating may be optimized for this purpose. In case of underfloor heating system, needed temperature is significantly lower than for DHW.

Size of building, number of apartments
This solution is suitable for any size of buildings with the preference for average and larger ones. Decentral direct electric DHW avoids heat losses in case of long piping systems in average or larger buildings.

DHW and storage characteristic
DHW is realised for each apartment separately through a direct electric heating system. No storage tanks needed. Energy distribution losses reduced to the minimum. Generally, the provision of DHW with heat pumps is more energetically efficient than a direct electric solution. Nevertheless, in some cases both solutions may be similar in term of global efficiently consideration.

Energy standard, insulation level
This concept can be generally used for buildings with all levels of energetical standards.

Complexity of installation
Easy installation of DHW heaters. No DHW tanks needed.

Heat Sources
All heat sources possible.

Specific issues of the concept
Heat pump only for heating. No distribution heat losses for DHW. Easy avoidance of legionella.

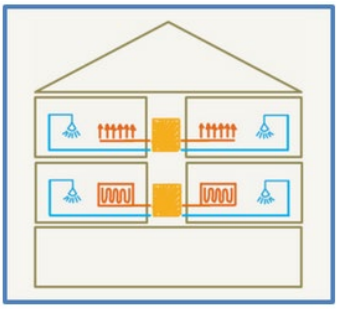
Positive aspects

- Low investment for DHW
- No distribution losses for DHW
- Optimised solution for heating

Negative aspects

- High electricity demand for DHW

3.1 One heat pump for a number of apartments



Main characteristic of the concept
One heat pump system for space heating and DHW for several apartments (usually grouped by levels or staircases).

Heat distribution and temperatures levels
The heat distribution occurs through the section of the building (usually a level or a staircase). Each heat pump provides heat for space heating, as well as for DHW.

Size of building, number of apartments
This solution is a typical solution in SFH, it will be common to implement in smaller MFB with small number of apartments. In case of large buildings more than 1 heat pump may be necessary to meet the required heating capacity (cascade solution).

DHW and storage characteristic
Storage tanks for DHW are needed. Separate consideration about legionella needed (for example ultra-filtration).

Energy standard, insulation level
This concept can be used for buildings with a high, as well as a low level of insulation. It may be applied as refurbishment of existing solutions with one heat generator for each level, which is a typical solution in several countries.

Complexity of installation
The complexity of the whole hydronic system of the building is reduced by using several hydronic circuits. Complexity is related to the space needed for each heat pump (several technical rooms), as well as their connection to the heat source.

Heat Sources
All heat sources possible. Depending on the position of heat pumps, some heat sources may be very difficult to implement. For example, it may be difficult to connect ground collectors if the heat pump it is not located on the ground floor. In some cases, use of outside air may be difficult due to the sound emissions or heat source capacity.

Specific issues of the concept
Several distribution circuits are necessary. Several technical rooms may be necessary to install the different heat pumps. Smaller capacity of each heat pump compared to the entire central solution.

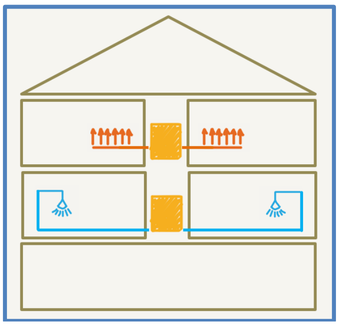
Positive aspects

- Smaller heat pumps applicable
- Less distribution losses than central system

Negative aspects

- Distribution of source energy through the building or
- Decentral noise of outside-air units
- More technical rooms needed

3.2 Apartments grouped by mode



Main characteristic of the concept
One heat pump system provides one mode (space heating or DHW) for a number of apartments (usually grouped by levels or staircases).

Heat distribution and temperatures levels
Heat pumps provide heat for only one mode for a section or several sections of the building. The temperature levels provided by the heat pumps are strictly connected to the mode (space heating or DHW). This solution doesn't provide an integral heat solution for the whole building.

Size of building, number of apartments
This solution is more suitable for average and especially for large buildings. In smaller buildings there is usually no need for grouping of apartments by mode.

DHW and storage characteristic
DHW based on heat pump is provided only for a section of the building (group of apartments). Heat pump must meet high temperature requirements of the DHW. Storage tanks for DHW are needed.

Energy standard, insulation level
This solution is rather suitable in refurbishment cases with lower energy standard. Not practicable for new buildings.

Complexity of installation
Using heat pumps for one mode only for a group of apartments reduce the complexity of each heat pump installation but increase the complexity of the entire heating and DHW system for the whole the building.

Heat Sources
All heat sources possible. Depending on the position of heat pumps, some heat sources may be very difficult to implement. For example, it may be difficult to connect ground collectors if the heat pump is not located on the ground floor. In some cases, use of outside air may be difficult due to the sound emissions or heat source capacity. For DHW ventilation exhaust may be used in some cases.

Specific issues of the concept
This solution allows partly retrofitting of the building. Need of additional heat generators (besides of heat pumps) to cover overall heat needs of the building.

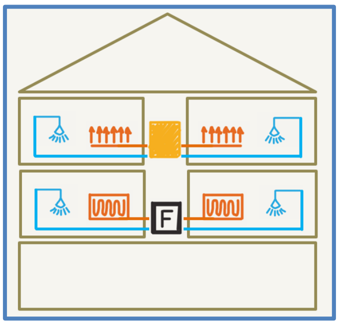
Positive aspects

- Allows partial retrofitting
- Splitting of functions results in optimised efficiencies

Negative aspects

- Existing systems remain for other apartments

3.3 Apartments grouped by heat generator



Main characteristic of the concept
The apartments are grouped by heat generators (usually grouped by levels or staircases)

Heat distribution and temperatures levels
The heat distribution occurs through the section of the building (usually a level or a staircase). The heat generators for each sector or group of sectors of the building differ. In sectors with heat pumps, each of them provides heat for space heating, as well as for DHW.

Size of building, number of apartments
This solution is more suitable for average and large buildings. In smaller buildings there is usually no need for grouping the apartments by heat generator.

DHW and storage characteristic
Depending on the sector of the building, the DHW is provided either by a heat pump or by other type of heat generator.
Storage tanks for the DHW are needed.

Energy standard, insulation level
This solution is rather suitable in refurbishment cases with lower energy standard. Not a favourited solution for new buildings due to use of fossil energy sources.

Complexity of installation
The complexity of the whole hydronic system of the building is reduced through using several hydronic circuits.
Complexity is related to the space needed for each heat pump (several technical rooms), as well as their connection to the heat source.
In case of retrofitting, exchanging heat generation for only a group of apartments at a time may reduce the complexity of the planned construction work.

Heat Sources
All heat sources possible. Depending on the position of heat pumps, some heat sources may be very difficult to implement. For example, it may be difficult to connect ground collectors if the heat pump it is not located on the ground floor. In some cases, use of outside air may be difficult due to the sound emissions or heat source capacity.

Specific issues of the concept
The solution allows for retrofitting of the building section by section.
May be convenient when retrofitting large buildings.

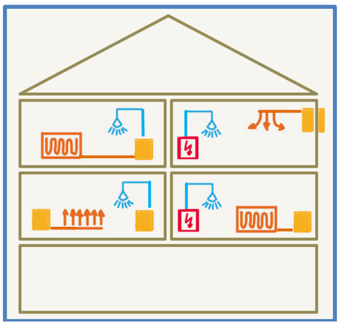
Positive aspects

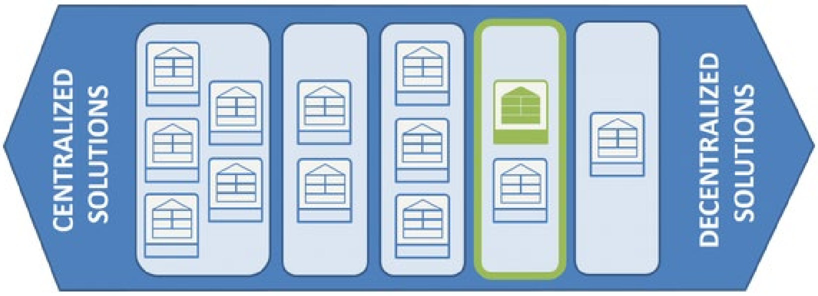
- Interim solution for larger existing MFB's in a phased approach or for partially renovated buildings.

Negative aspects

- Distribution of source energy through the building
- Decentral noise of outside-air units
- As final solution a substantial use of fossil fuel remains

4.1 Individual solution for each apartment





Main characteristic of the concept
Each apartment has individual concept of space heating and DHW.

Heat distribution and temperatures levels
The heat distribution is done separately for each apartment and specific to the chosen solution. The same applies to the temperature levels.

Size of building, number of apartments
Single apartment solution is a very flexible option. Rather not applicable for buildings with large number of apartments. It may be a good solution if the ownership of each apartment is individual, and it is difficult to find a common agreement among the owners of apartments.

DHW and storage characteristic
DHW is realised for each apartment separately. In some cases (for example direct electric DHW preparation) no storage tanks needed.

Energy standard, insulation level
This solution is rather suitable in refurbishment cases. In new buildings with higher energy standards, more systematic solutions advisable.

Complexity of installation
The effort of refurbishment of heat generators may be reduced to single apartments. No need for works for the whole building at once.
No heat distribution system throughout the building is needed. Nevertheless, enough space is required in each apartment for the installation of the heat pump.

Heat Sources
Outside air is the most probable heat source for the heat pumps solution for each apartment. Exhaust air can be used for specific types of application.

Specific issues of the concept
Very flexible solution if the refurbishment of the building is not possible for all apartments at once. No heat distribution system throughout the whole building is needed.

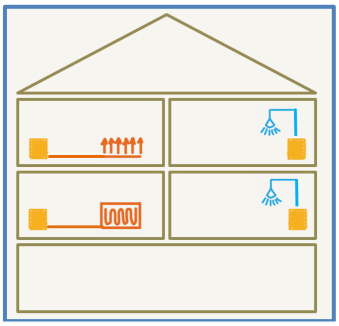
Positive aspects

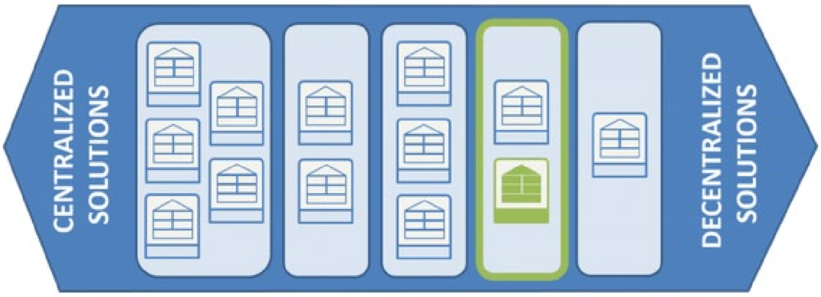
- Flexible solution, especially in case of individual ownership
- No distribution losses

Negative aspects

- Distribution of source energy through the building or
- Decentral noise of outside-air units
- Space requirement in each apartment

4.2 One apartment - one mode





Main characteristic of the concept
Decentral heat pump for one mode for one apartment.

Heat distribution and temperatures levels
Because of separate provision of heating and DHW, the temperature levels may be adjusted for each mode. The heat distribution is limited to each apartment, resulting short piping and low heat losses.

Size of building, number of apartments
The size of the building is not particularly relevant for this solution. More the ownership of each apartment and the difficulty to find a common agreement among the owners of apartments. In some cases, it may by a first step towards exclusive use of renewable energy

DHW and storage characteristic
DHW is realised with heat pumps only in selected apartments. In other ones, additional solution must be applied. The size of DHW storages may by reduced. Possibility to adjust of DHW temperature for individual needs of the inhabitants.

Energy standard, insulation level
This solution is rather suitable in refurbishment cases. In new buildings with higher energy standards more systemic solutions are advisable.

Complexity of installation
The effort of refurbishment of heat generators may be reduced to single apartments. No need for works for the whole building at once.
No heat distribution system throughout the building is needed. Nevertheless, enough space is required in each apartment for the installation of the heat pump.

Heat Sources
Outside air is the most probable heat source for the heat pumps solution for each apartment. Exhaust air can be used for specific types of application.

Specific issues of the concept
No heat distribution system throughout the whole building is needed, since heat pumps are installed in individual apartments. Space for the heat pumps required in each apartment.
Very flexible solution. Need of other heat generators to cover overall heat needs of the building. May be noisy.

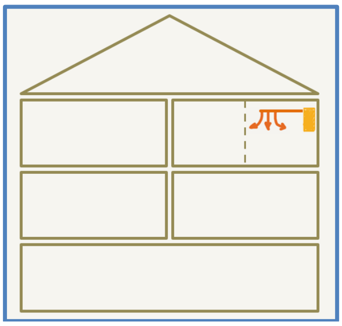
Positive aspects

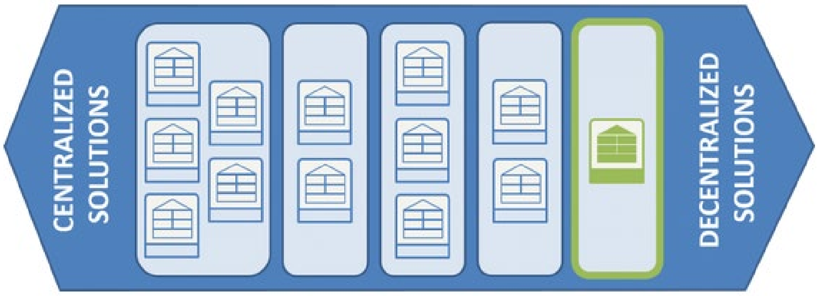
- Flexible solution, especially in case of individual ownership
- No distribution losses
- Splitting of functions can result in optimised efficiencies

Negative aspects

- Distribution of source energy through the building
- Decentral noise of outside-air units
- Space requirement in each apartment

5.1 Heat pump for individual room





Main characteristic of the concept
One heat pump for space heating (or cooling) for one room of the apartment.

Heat distribution and temperatures levels
The heat distribution (heating only) occurs exclusively through air. This also offers the opportunity of providing cooling in summertime. Since it's a modular and local system, there is no heat distribution throughout the building.

Size of building, number of apartments
Very flexible solution for covering heating (and possible cooling) needs. Rather not applicable in large buildings. Strong architectural limitation in existing buildings. For new buildings possible integration in the building façade.

DHW and storage characteristic
Separate system is required for DHW.

Energy standard, insulation level
This concept can be used for space heating in buildings with a high or intermediate energy standards. The heating capacity is limited due to the use of relatively small heat pumps units.

Complexity of installation
The complexity of installation is very low for each unit. Usually, no need for leaving the apartment in case of refurbishment.

Heat Sources
This system uses outside air as a source and will preferably be operated with air as the transfer medium for space heating.

Specific issues of the concept
Heating only. Need for other solution for DHW.
Heat distribution occurs exclusively through air.
May be noisy.

Positive aspects

- Flexible solution for smaller MFB's, especially in case of individual ownership
- No distribution losses

Negative aspects

- Decentral noise of outside-air units
- Additional solution for DHW needed

6. Summary of Task 4

One of the main achievements of the Annex 50 is the collection of case studies showing the implementation of heat pumps in multi-family buildings in all countries participating in the Annex.

Figure 8 shows the interactive map with indicated locations of collected case studies. The map is available on the Annex 50 website free for all users. So far, 35 examples have been included and described according to a standardised method. Each case study indicated on the map has a dedicated website with a detailed description of the case, as well as a 2-page pdf file free to download. The structure consists of two pages. The first page gathers the main information about the project and shows pictures of the object. On the second page, it is possible to find more information on the technical concept, as well as a hydraulic scheme if available.

The results achieved within the Task 4 are a good example of a successful cooperation between several Annexes. Some of the examples (several cases from Switzerland) implemented in the case studies database have been elaborated within the Annex 49 "Design and integration of heat pumps for nZEB (nearly Zero Energy Building)".

The elaborated case studies are also linked to the certain examples of solutions from the classification described in the "Task 3" section. Through providing concrete examples, the theory has been brought to the practice.

The significant effort to create the database and to find case studies should not be terminated with the end of the Annex 50. This is in particular in the light of the fact that several countries are currently in the process of completing new cases. Therefore, one of the goals of the planned Annex "Heat pumps for multi-family residential buildings in cities" is to extend the case studies database with the goal to create a leading database of heat pump applications in multi-family residential buildings.

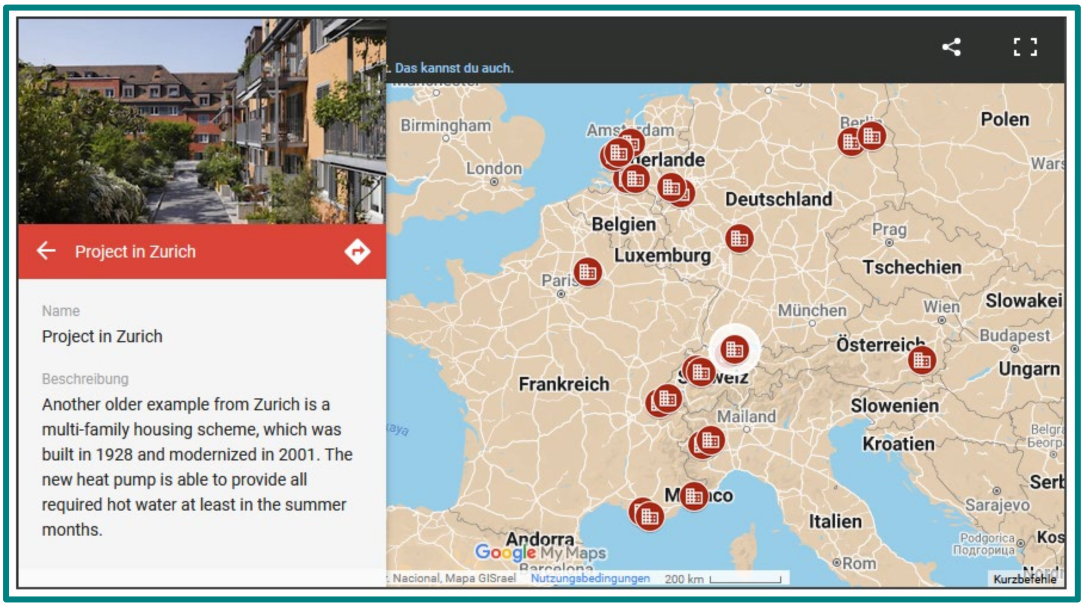


Figure 8: Case Studies Map (https://heatpumpingtechnologies.org/annex50/case-studies/)

List of case studies examples divided by the country of origin (for detailed description of the case studies is to find in the Appendix 4, as well on the Annex 50 website):

6.1. Austria

- "Hot Ice Wize" is focused on the use of latent heat with two ice storages and two heat pumps in combination with unglazed solar collectors and a PV system. It is designed as a pilot project for local heat supply
- Vögelebichl multi-family houses are the first in the world responding to the Passivhaus Plus Standard. Furthermore, the buildings were designed to achieve the annual net-zero energy balance thanks to on-site renewable energy generation. "Vöglebichl Multi-Family Passive Houses" are in Innsbruck, Austria
- The residential building "D12" is a block of 7 buildings with 4-6 storeys each, commercial use on the ground-floor (GF) with 8 shops on 900 m2 and 213 flats on the upper levels. The (conditioned) gross floor area is about 20,600 (19,080) m2. The building is located in Vienna/Aspern Seestadt.

6.2. Denmark

- Mørkov, Zealand. The project is a part of 3 projects, where cluster houses where energy renovated in 2013. The heating supply is built up in the same way and is hybrid solution with an Air/Water heat pump and a gas boiler as a backup. In two different semidetached cluster house buildings rented out for tenants is heated with heat pumps combined with gas boilers implemented.
- Svinninge, Zealand. The four cluster houses rented out for tenants is situated in a U-shape with 5,2,5 and 6 apartments. The houses are built in 1985 and the size of the apartments varies from 50 to 70 m^2.
- Espergærde, North Zealand. The project consists of 4 apartment buildings, with 33 private apartments mixed with some business area in the ground floor level. The focus is on high efficiency, minimal sound level and design. The heating is delivered by Air/Water heat pump.
- Noerrelundparken Ribe, Southern Jutland. The project consists of 42 private apartments, which are placed in 9 connected buildings placed in a horseshoe shape two separate buildings with shared facilities are also heated. The heating is delivered by a 43 kW ground source heat pump and a 310 kW boiler. Even though the capacity of the heat pump is only 12 % of the total heating capacity does the heat pump deliver 46 % of the total heat consumption.
- The hotel building Charlottetårnet in Copenhagen is a building with 16 floors and 37 hotel apartments, 2 apartments at each floor, designed in 2011. The building has a large façade area compared to the floor area. To reach a low energy consumption was heat pumps and natural ventilation included as a solution in the design phase.

6.3. France

- A new built private housing is located in Marseille, in the South-East of France. The hot water production is arranged by a solar heat pump. For this installation, climate and sunshine are very favourable. Thus, solar panels are installed on the building roof.
- The district heating system, specific to this eco-district in Roquebrune Cap Martin (Nice) is quite innovative. It is based on the treated water rejected by water treatment plant located 500m far from the eco-district. This water is used as the cold source of 8 heat pumps for DHW

production and 5 heat pumps for heating and cooling.

- In Soissons, heating is supplied by a renovated district heating grid connected to a wood-fired heating plant. The DHW production was ensured by individual electric water heaters until now. The replacement of these by a collective heat pump induces a 50% reduction on the electric bill due to DHW production.
- Opened in 2018, a senior-living building in La Ciotat is another good example for heat pumps in civilian residential buildings. A 60m² solar panel is providing energy for the two heat pumps.

6.4. Germany

- Over a net floor area of 3248 square meters a heat pump cascade system provides warm water, pleasant room temperatures and enough energy for the catering business on the ground floor of the new holiday home “Boarding House Potsdam”.
- Between 1881 and 1966 children were taught inside this old school building in Kempen, which is now listed. In the meantime, the building served as a church, community administration and youth hostel. In 2008, the house was finally rebuilt by its new owner into a multi-family house with five residential units. After the existing building had been heated over the years with an oil heating and district heating, the decision was made to use a heat pump as an environmentally friendly solution.
- If former industrial and commercial areas are overbuilt, entire districts are often created in a very short time with a distinctive atmosphere and modern flair. This is also the case in the Düsseldorf district of Derendorf, where the discarded freight yard makes way for the “Neues Düsseldorfer Stadtquartier”, which heavily relies on heat pumps.
- Not infrequently, new buildings attach great importance to efficient insulation and environmentally friendly energy production. In Bruchköbel, the builder himself, with the help of his own construction company, has set himself the task of equipping his new building with advanced energy systems.
- Seven new buildings were built in Petershagen in northern Germany, each with a heat pump and photovoltaic systems on the roofs. Six of them contain apartments that are specially adapted to the needs of older people and the seventh is a community building.
- These two buildings form part of a cluster of five large renovated multi-family buildings from the 1960s within the Karlsruhe district Durlach, where an integrated energy system is demonstrated within the research project “Smart district Durlach”, Ersinger Street 2 and Ersinger Street 4.
- In August of 2015 the five-storey multi-family residential building (17 apartments) was commissioned. The all-electric building is equipped with a 50 kWth electric brine-water heat pump that uses a total of 85 m2 of solar absorber in addition to an ice storage as heat source. The “nZEB multi-family houses” are located in Riedberg, Germany.

6.5. Italy

- 3 apartments building in Turin. The project is focused on a hybrid design between solar thermal collectors, heat pump and a gas boiler. It is a renovation operation which successfully combine existing solar system with an in-series combination of gas boiler and air source heat pump.
- 60 apartments not retrofitted building in Turin. The project is focused on a hybrid design between an air source heat pump and two gas boilers. It is a renovation operation which successfully combine a gas boiler and

air source heat pump in parallel in order to minimize the energy consumption especially during mid-season.

6.6. Netherlands

- Second Skin – community of Vlaardingen (Rotterdam). In 2017, 12 portico houses have been renovated according to the 2ndSKIN concept into "Zero Energy"-houses. The portico houses originally date from 1952 and have been thoroughly renovated including three-layer insulating glass. The new façade has an extra shaft for the two central heat pumps (each one separate for 6 apartments) and associated pipework. The source for each heat pump is a vertical GSHX (BTES) of 175 m deep.
- “Jacques Urlus Plantsoen” – city of Leiden. In this project two MFBs of 200 apartments each and an elderly care centre (all non-renovated buildings) in 2018 were equipped with a high temperature HP of 1500 kW_{th} to replace the existing CHP gas engine and gas boilers. The HP can deliver 85 °C peak supply during wintertime for space heating based on an ATES system. In autumn and spring outside air is used as HP source. DHW is also provided by the HP on a temperature of 65 °C.
- “Sculptures” – city of Breda. The Sculptures complex was delivered in 2012 and consists of a total of 283 apartments, including 245 regular apartments and 35 care apartments. There is also 3,500 m^2 of common care, including 4 psycho-geriatric departments. The base load of space heating is delivered by a water-to-water HP of 300 kW_{th} with ATES as source. DHW is produced by 200 m^2 of thermal solar collectors and HE gas boilers. These gas boilers also deliver the peak load for space heating. Free cooling during summertime is delivered by the ATES system. The houses and the care departments have underfloor heating.
- “Hoog Lindoduin” – community of Scheveningen (The Hague). The deep renovation of this 14-story building with 182 apartments was finalised in 2021, almost 60 years after its original construction. In the renovated building each apartment has its own HP which delivers space heating and DHW. The source is a collective BTES system consisting of 60 GSHXs of 250 m each, also providing free cooling during summertime.
- “Sophia Staete” – community of Hendrik Ido Ambacht. Sophia Staete is a new residential care building delivered in 2013 of approx. 13,000 m^2. Two central HPs deliver 35 °C supply for space heating and source energy for 74 separate DHW-booster-HPs in each apartment. The central HPs use ATES as source system, which is regenerated by low temperature thermal solar collectors (Energyroof)
- “Leyhoeve” - city of Tilburg. The Leyhoeve complex was delivered in 2016 and consists of 285 care apartments. The apartments are spread over six floors and have a total gross floor area of 39,650 m^2. 3 variable speed piston HPs of 200 kW_{th} each with BTES as source system produce heating and cooling. DHW of 72 °C is delivered by 3 high temperature HPs of 100 kW each (also variable speed piston types) which use condenser heat of the BTES HPs as source.

6.7. Switzerland

- The project in Daru, Geneva concerns the replacement of an existing gas heating system by a bivalent heat pump and natural gas solution in an existing multi-family building. With the goal of having the maximum annual heat production from HP origin, six cascaded air/water heat pumps (6x24kW @A-7/W60) were implemented on the rooftop.
- The project in St. Julien, Geneva concerns the replacement of an existing oil heating system by a HP only solution in a multi-family building. With the goal of having the total heat production from HP origin,

two air/water heat pumps were implemented on the rooftop (in total 250kW @ A-7/W65). One of the previous fuel oil boilers was kept as a back-up. The building envelope was not renovated.

- In Zurich, three heat pumps were built on top of a residential building dating from 1982 that was entirely renovated in 2016. The renovation works also included the addition of new floors, windows, insulation, solar panels and air conditioning. The heat pumps have a installed capacity of 3x32.85kW @A2/35.
- Another example from Zurich is a residential area consisting of 12 multi-family houses, which were built in 1928 and partially modernized in 2001. The new heat pump (95kW @ A10/W40) is able to provide all required hot water through the summer months and about 35% of the global heat needs distributed through a local thermal network. The make-up heat production is generated by a gas boiler.
- In Bern, an old oil heater was replaced by an outdoor heat pump unit (50kW @ A2/W35) in a building from 1993. As the heat pump is not located inside the building, the heat is transported to the apartments by a pipe system.
- Another example located in Bern concerns 3 connected buildings from 1963 that were entirely renovated in 2013 to the Minergie-P norm. The workers improved the insulation, changed the windows, and added two air/water heat pumps. The solar panels on the roof can provide 148% of the required energy for the 18 households, hence making it a positive-energy building. The installed power of the heat pumps is 2x24kW (A2/W35).
- The first MINERGIE-A® building with office use in canton ZH, located in Uster, has been monitored for two years from May 2014 – April 2016. The all-electric building is equipped with a 33.1 kW ground-source heat pump (B0/W35) a 24 kWp solar PV-system and a 7.1 m2 PV/T-collector for domestic hot water (DHW) preheating.
- The multi-family house has four apartments and is equipped with a geothermal heat pump with two bore- holes of 225 m each for space heating and DHW production. The multi-family plus energy building Allmendholz is in Horgen, Switzerland.

7. Website

The Website of the Annex 50 is not only a typical and mandatory tool for communication about its progress and for dissemination of written materials but an integrated part of its results. As such, the website must be considered as an integral part of the final report of the Annex 50.

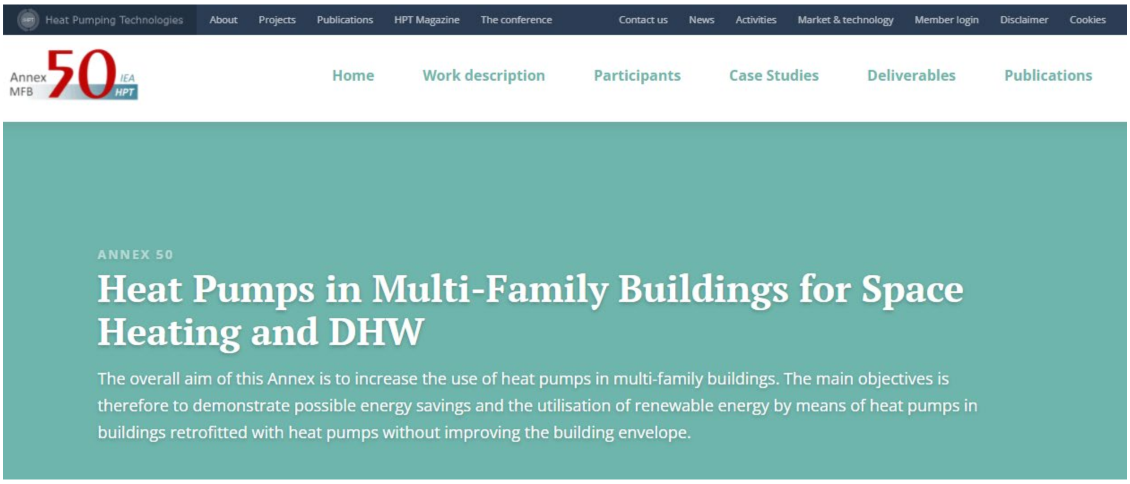


Figure 9: Website of the Annex 50 (https://heatpumpingtechnologies.org/annex50/)

7.1 Web-based tools

Apart from the standard content of the “Annex-Website”, such as news, structure of the projects, description of the partners or download area with the documents, the Annex 50 website offers direct “tools” for dissemination of the achieved results. There are two major parts of the website presenting the results. The first one feeds on the results from the Task 3 and allows for browsing through the “solution matrix”. The second one (described in the section 6) allows for browsing the case studies collected within the Task 4. Both parts can be used separately but they are also connected with the aim to show the practical, realised implementations of the theoretical solutions.

7.2 Browsing modes of the “solution matrix”

The advantage of description of the content collected within the Task 3 in a matrix format (13 solutions described in a standardized way according to 8 categories) is that it is polyvalent in the way it can be used.

Presentation of the information is corelated with the needs and the knowledge level of the users. Various options to navigate and access the information content can be shortly described as: “All you can eat”, “Comparing solutions” and “Solution finder” mode.

In the moment of the finalization of the present report (March 2022) the first browsing mode is available on the website (https://heatpumpingtechnologies.org/annex50/solution-matrix/). The implementation of the modes “Comparing solutions” and “Solution finder” is ongoing. Finalisation of all browsing modes to the full extent is planed within the new Annex.

“All you can eat” browsing mode

The first option allows users to access the information by navigating freely, when willing to learn about any or all results without searching for a specific solution.

By choosing this mode from the starting “general description” webpage, a list of all the “families” and “family members” is displayed along with a brief description of each solution. By choosing the “Full description” button, the user is directed to the corresponding fact sheet giving a detailed overview of the selected concept. From there, a “See example of case studies” button leads to information on realized cases (if available for this solution). The solution factsheets and the case study sheets are available for downloading.

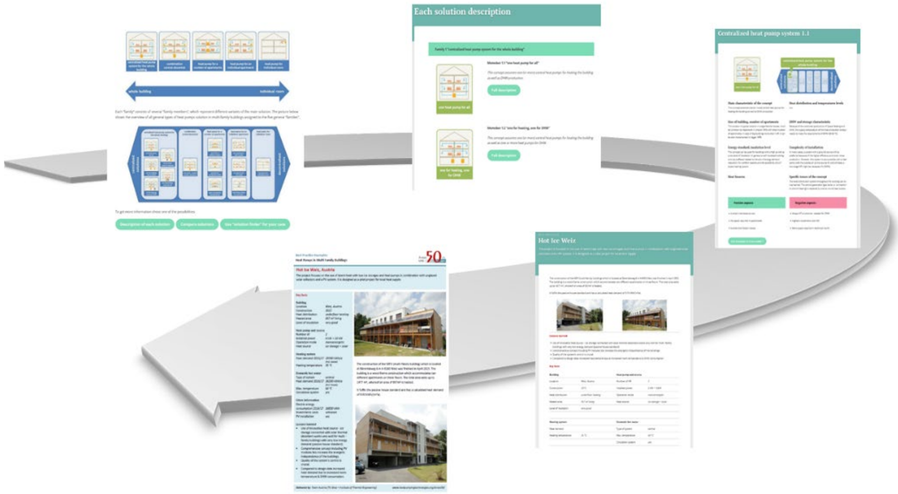


Figure 10: “All you can eat” browsing mode ilustration

“Comparing solutions” mode
This second navigation option is adapted for users willing to compare certain solutions with each other.

By choosing this mode from the starting “general description” webpage, a table of all the “families” and “family members” is displayed. By clicking a selection of boxes, the chosen solutions can easily be compared with each other, appearing side by side. All other functions (fact sheet giving a detailed overview of each of the selected concept, information on realized cases, documents for download) are identical with the first browsing mode.

“Solution finder” mode
This third navigation option is designed to help users to find suitable solutions for a specific situation.

By choosing this mode from the starting “general description” webpage, the users are directed to a set of selection criteria from which they are invited to choose (for example size of the building, energetical standard of the building, preferred operation mode of the heat pump, heat source). The combination of criteria leads to suggested solutions which are potentially suitable options. All other functions (fact sheet giving a detailed overview of each of the selected concept, information on realized cases, documents for download) are identical with the first browsing mode.

Additionally, this mode will be extended by a set of typical cases (for example large multi-family building with a high energy demand) and a selection of suitable situations.

8. Discussion

The results of the Annex 50 have been achieved with the best knowledge and belief of the partners. Nevertheless, presented outcomes may certainly possess some shortcomings.

The description of the proposed “solution matrix” should rather be seen as a framework prepared for further elaboration than as an accomplished task. Each description is a compromise between various views of the involved Annex partners. In some cases, a specific national perspective results in a different view on the topic. It is recommended to open the discussion about the characteristic of each concept to the broader audience.

With the simplified approach chosen to classify and to describe the solutions, the planed tool “solution finder”, suggesting particular solutions for certain types of buildings etc., cannot be seen and used as a “pre-planning” tool. It is and will be, even with further improvements, solely a hint-assistant on the way to find the right solution and to see existing possibilities.

The case studies database should be regarded as a well-established tool with a large expanding potential. The collected cases show explicitly the applicability of heat pumps in multi-family buildings. Despite the significant effort, with the information at the disposal it was not possible to ensure that all case descriptions are of the same level of detail and completeness. The data base should be further developed with more case studies in order to reach its full potential.

Overall, it is highly recommended that the work continues and builds upon the results already achieved.

9. Conclusions

The importance of implementation of heat pumps in residential buildings, and in multi-family buildings in particular, has grown significantly in the last years and has even further intensified in the days of the crucial and unprecedented debate on independency from fossil energy sources. It`s undeniable that heat pumps technology will play a key role to achieve both the climate neutrality and the fossil fuels independency.

From this perspective the work performed in frame of the Annex 50, together with the achieved results can be classified as very relevant and useful.

The main message from the Annex 50 work is that the use of heat pump systems in apartment buildings is possible and already practiced, as showed by many examples from several countries.

The variety of multi-family buildings and their characteristics make it possible to apply various technical solutions based on heat pumps. Nevertheless, the large heterogenicity of the multi-family buildings leads to individual solutions which are difficult to apply on a large scale. More standardisation of the products and the solutions is therefore needed and crucial.

The proposed categorisation and a simplified schematic visualisation of heat pumps solutions in multi-family buildings provides a user-friendly entry point for the building's owners and/or decision-makers. Rephrasing, it can be the first step towards implementation of heat pumps by disenchanting the complexity of the possible solutions.

In parallel to the positive messages, it must be stated that they are still several obstacles to overcome in order to implement heat pumps in multi-family buildings, and in particular those existing and non-retrofitted. These obstacles are both of a technical and non-technical nature. On the technical side there can be a sufficient heating capacity and supplied temperature, as well access to the heat sources. Investment costs and a complex ownership structure are an example of non-technical obstacles.

Concluding, the continuation of the work initiated with the Annex 50 would be highly beneficial towards broader implementation of heat pumps in multi-family residential buildings.

10. References

[1] IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.

[2] IEA (2021), Net Zero by 2050, IEA, Paris https://www.iea.org/reports/net-zero-by-2050

[3] Cambridge Econometrics, 2022: Modelling the socioeconomic impacts of zero carbon housing in Europe, Technical Report, Cambridge, UK

11. Appendix/Appendices

All Appendixes are available on the website of the Annex 50.

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