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General classification of heat pumps solutions for multi-family buildings

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Abstract

The paper documents the results of the IEA HPT Annex 50 "Heat Pumps in Multi-Family Buildings for Space Heating and DHW" and it is based on the final report of the Annex 50. The active Annex group consisted of seven countries (Austria, Denmark, France, Germany, Italy, Netherlands, and Switzerland). The working group has succeeded in creating a general classification of heat pumps solutions for multi-family residential buildings. The solutions have been defined in a standardized way according to eight representative categories. Overall, 13 solutions have been identified, ranging from a fully centralized to a completely decentralized system (each-room solution). The solutions have been grouped into five "families", each grouping specific sub-solutions. In parallel to the theoretical classification of solutions, the Annex collected numerous case studies representing implementation of heat pumps in multi-family buildings. 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. For each case study, a corresponding theoretical solution has been defined. All these elements reflect the holistic approach of the Annex, which encompasses the definition, categorisation and the practical implementation of heat pump solutions.

Keywords: multi-familiy buildings; classification of solutions, centalized systems, decentralized system

1. Introduction

The goal 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.

In light of the above considerations, 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 [2, 3].

Most heat pumps installed in Europe are dedicated for single family houses. To reach the climate protection goals, heat pumps must be installed also in multi-family buildings. The analyses provided in the final report of Annex 50 [4] show clearly that one of the major barriers of a broader application of heat pumps in multi-family buildings is a deficit of knowledge. Both on the side of owners of the buildings or apartments, as well as investors.

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. There are even combinations of ownership by housing corporations and private owners in one building. This implies extra challenges at organizational, financial and implementation level.

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Annex 50 was covering a comprehensive range of topics which relate exclusively to multi-family buildings. A variety of key aspects for usage of heat pumps in multi-family buildings has been considered within this Annex. The outcome allows to better understand the technical and non-technical barriers, comprehensively presents different theoretical solutions of heat pumps implementation in multi-family buildings and visualises numerous case studies with their practical implementation. The connection of theory and the real implementation was an important factor during the whole work within the Annex.

2. National situations

In Europe, the market for heat pumps (HPs) in residential buildings has been steadily growing for several years in most countries [5]. However, this overall trend does not reflect various situations in different types of buildings. Whereas in new individual houses HPs are the most spread solution, their market in multi-family buildings (MFB), both new and existing, remains low.

The first task of Annex 50 was to collect and analyse data from the participating countries with a view to identifying country-relevant characteristics of buildings, their technical aspects and legal regulations relevant for application of heat pumps in MFB.

The shares of individual and collective housing are quite similar among the countries and encompass from 45 to 50% of dwellings in multi-family buildings. In almost all countries, most of multi-family buildings are composed of less than 10 flats; 6 to 8 in average.

In all countries, the multi-family buildings stock is almost equally distributed between owners and tenants, with a slight majority of owners. In all countries participating in the Annex 50, the residential building stock is quite old, with an average share of 52-60% of buildings built before 1970. The main consequence is that space heating constitutes the largest part of energy consumption with a share of about 65%. For old multi-family buildings (<1970), it represents a yearly heating demand of 120-150 kWh/m^2.

Apart from the age of the buildings and an average number of appartements, also the energy carriers for providing the heating needs varied in analysed countries (Figure 1). Natural gas is the main energy source for heating in multi-family buildings in most analysed countries. In France and Switzerland there is a significant share of direct electrical heating. Denmark is the country with the biggest share of district heating (followed by Austria). Switzerland is the exception with more than 50% of oil heating systems.

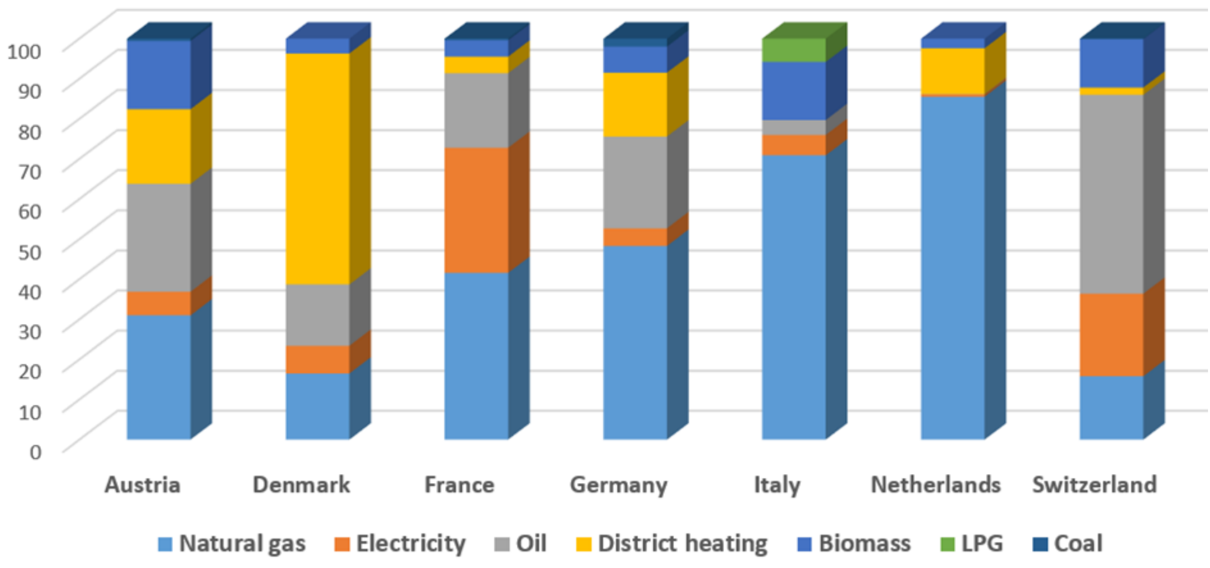


Fig. 1. Energy carriers for providing heating and domestic hot water production in selected European countries

3. Translating complexity

The diversity of 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.

In the first attempt, the working group tried to create possibly exhaustive categorisation taking into account of various perspectives, such as level of centralisation, heat sources, type of hot water production, energy standard of a building, size, etc. The visual result of this endeavour represents Figure 2 (it is not the intention to show the content of the classification but only its complexity). Although from the scientific and technical point of view the achieved classification was satisfying, its complexity constitutes an obstacle for a readability and comprehension of various possibilities.

To overcome this problem, the Annex 50 group proposed a simplified categorisation of possible heat pumps implementations in multi-family buildings described in following paragraphs. The working group of Annex 50 is aware of the fact that choosing a simplification over completeness results in some of the aspects not being described and presented sufficiently broad and exhaustive. The oversimplification may even be seen as disturbing and artificial, but this approach has a clear goal to "translate complexity". Discussions with the housing industries confirm the need for such simplified classification. To see the potential possibilities in an easy and understandable way can be crucial for taking decisions by building's owners or buildings administrators, who very often do not possess sufficient knowledge and experience to comprehend the complexity.

It is to be mentioned that the way to propose the simplified categorisation was a difficult challenge. The final outcome is a result of longstanding discussions and compromises acknowledging the technical and scientific shortcomings of this approach.

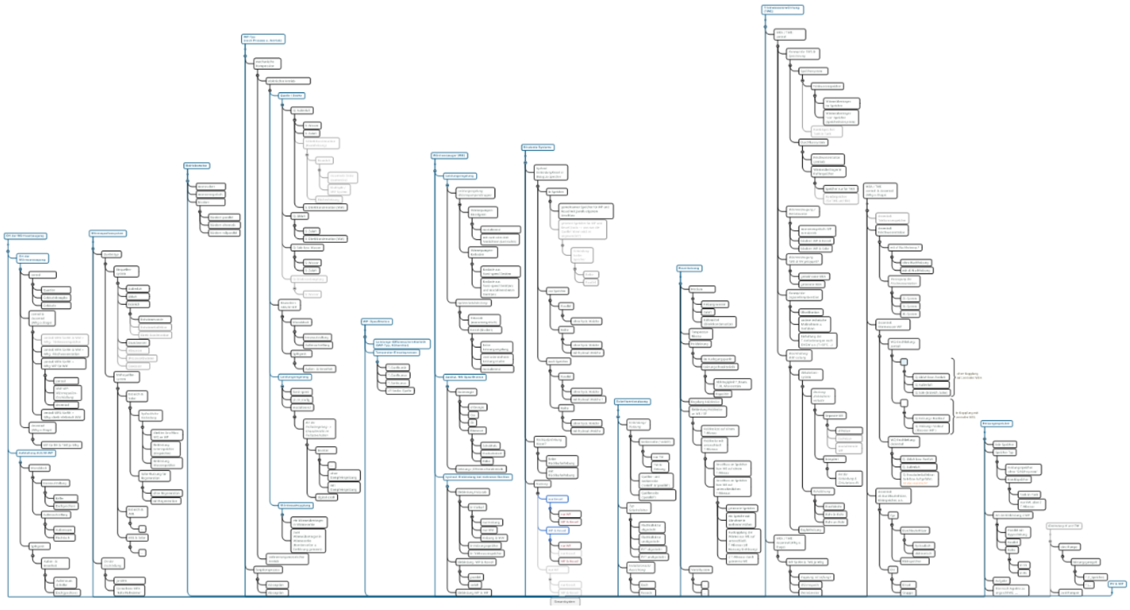


Fig. 2. Visual example of a comprehensive classification of heat pump solutions in multi-family buildings (it is not the intention to show the content of the classification but only its complexity).

4. "Solution matrix"

During the process of gathering knowledge and practice, the work group faced a rich variety of cases and characteristics to consider. Depending on the focus of the system design, for instance, 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.

4.1. 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 aligned by their level of system centralization in the following schematic drawings (Figure 3).

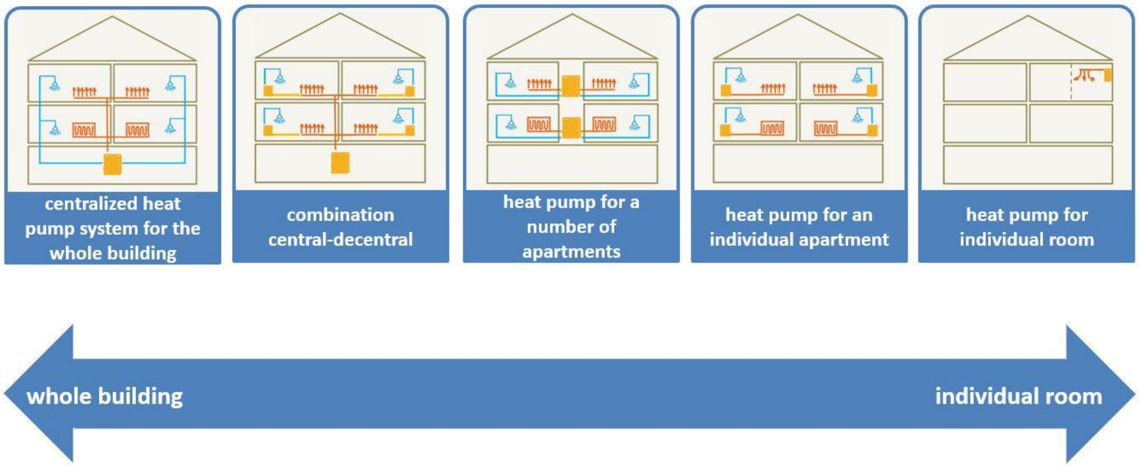


Fig. 3. General classification: solution families

Each “solution family” comprises of several “family members”. The members are variations within one logical group (Figure 4).

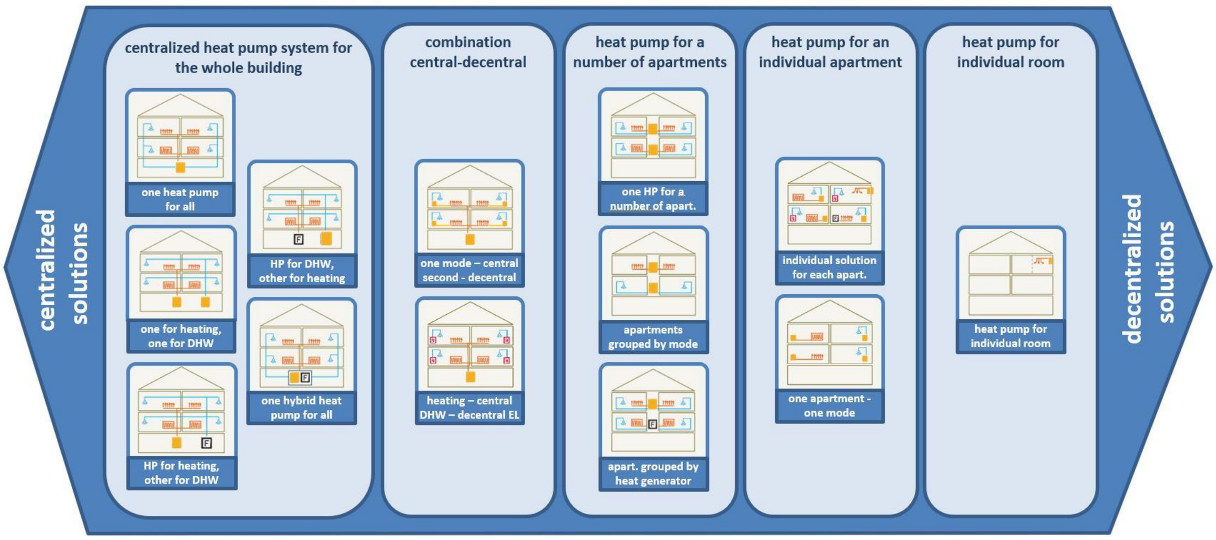


Fig. 4. The overview of the 13 resulting solutions sorted by families according to their degree of system centralization

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, another 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.

4.2. Solutions description

All solutions listed in the above paragraph have been described in detail within 8 categories listed below. The standardized categories allow for a better comparison of solutions.

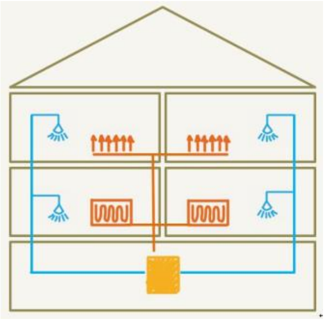
- **Main characteristic of the concept**
  Maximally concise description of the solution
- **Size of building, number of apartments**
  This category indicates for what size of the building the solution is favourable. For the sake of clarity, three categories of the buildings have been defined. Depending 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.
- **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.
- **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.
- **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.
- **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.
- **Complexity of installation**
  The estimated effort for the installation of the system is described in this section.
- **Specific issues of the concept**
  Any additional information about the solution finds its place under this category.

4.2.1. General remarks to the concept's description

Significant simplification of the presented categorization allows for a quick and understandable overview of heat pump solutions for multi-family buildings. The description of each category is deliberately short and simplified, to be comprehensible for broad audience. This approach consequences with technical superficiality. Presented descriptions do not aim at being fully exhaustive. They rather form a basis for further discussions. 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. Some descriptions within solutions from the same "family" repeat.

4.2.2. Example of the solution´s description

Comprehensive description of all solutions is available either on the website of the Annex 50 (https://heatpumpingtechnologies.org/annex50/) or in the final report of the project [3]. Below example presents the solution 1.1 called „one heat pump for all“



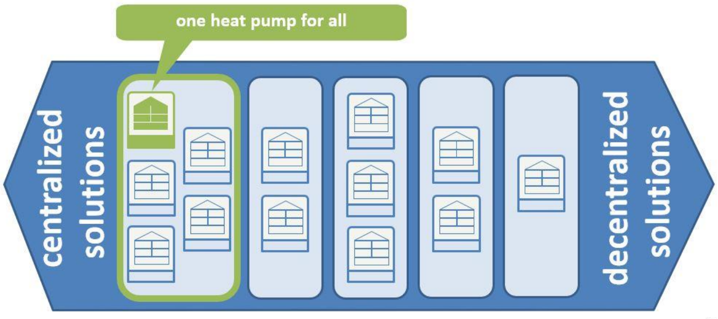


Fig. 5. Schematic hydronic system of the solution and the placement in the "solution matrix"

Description according to the eighth categories:

- **Main characteristic of the concept**
  One central heat pump system for the whole building, both for space heating and DHW.
- **Size of building, number of apartments**
  This solution is a typical solution in SFH (single family house). 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).
- **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, however more challenging to implement.
- **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 the technical room. For larger systems, the sound emissions may be a problem for air-source heat pumps.
- **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.
- **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).
- **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.
- **Specific issues of the concept**

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

In addition to the eight categories, the main advantages and disadvantages have been identified. Similarly here, to concisely indicate strong and week sides of the concept was a balancing act between shortness and comprehensiveness. In case of the example solution 1.1. the positive aspects are: optimal for smaller MFB's, one controller, existing distribution maintained and simple replacement of a gas boiler. The negative aspect are the high thermal distribution losses.

5. Holistic approach to present the results of Annex 50

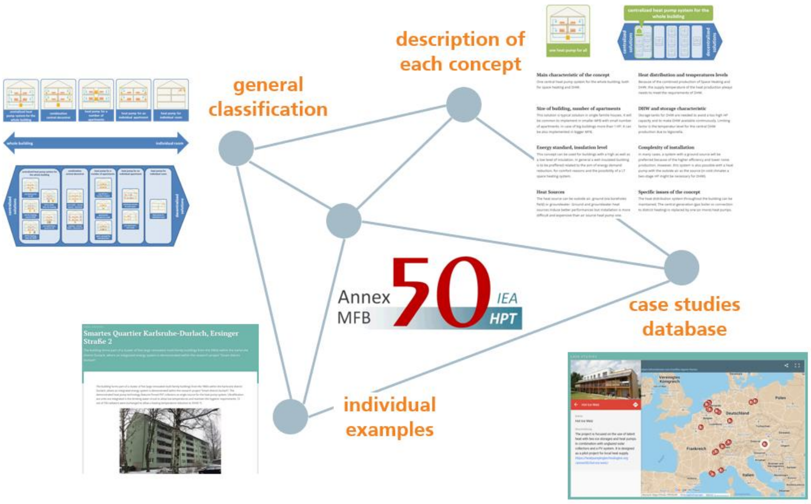


Fig. 6. Main elements of the "solutions matrix", the holistic result of the Annex 50

The approach of the Annex 50 was to find the way to create a holistic (integrated) method of presenting its results. The categorisation of the solutions and the description of each of them is only a part of the "solutions matrix". Other parts are the case study database and the individual examples of case studies of heat pumps in multi-family buildings. Each part of the matrix can be used or presented as a stand-alone component. Figure 6 shows the schematic connection between each component of the matrix.

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

6. Discussion

The results of the Annex 50 have been achieved with the best knowledge and belief of the project partners. Nevertheless, presented outcomes may certainly be flawed with 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 planned 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 recognise 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.

7. 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.

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.

The work of Annex 50 will be continued in the newly initiated Annex 62 "Heat pumps for multi-family buildings in cities" (started in January 2023 with the planned duration of 3 years). The tools described in the paper will be consequently improved and developed. Furthermore, new aspects of the application of heat pumps in multi-family buildings will be addressed.

Acknowledgements

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