Pre-Check for heat pumps: comparison of heat sources for heat pumps

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Abstract

As a result of the increasing use and implementation of heat pumps the number of usable low-temperature heat sources and heat transfer systems for heat pumps that are available on the market rises. Ice storages, air fences or high performance energy piles are used and sold without having scientific knowledge about performance and the cost-benefit ratio of these systems. In order to obtain an energy-efficient and economic operation of the heat pumps, it is necessary to have an optimal design of the heat pumps including the choice of the heat source and the connection to the building itself.

The research project "future:heatpump", funded by German Federal Ministry for Economic Affairs and Energy, is dedicated to the energetic and economic evaluation of heat sources for heat pumps. In this context, a pre-check-tool for preselection of heat sources and suitable heat transfer systems is developed. The holistic comparative analysis of different heat sources and heat transfer systems relates to the SPF of the heat pumps, the extraction and injection capabilities of the heat exchangers and the general performance of the systems. In addition, an evaluation of economic and environmental aspects is made. The aim is to determine the plausibility of the application and the specifications of the different source systems. To validate the tool’s input and outputs, measurements are performed on several systems and heat sources.

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Keynotes: heat pump, heat sources and heat transfer systems / heat exchanger, pre-check-tool

1. Introduction

The use of heat pumps for heating and cooling of buildings is becoming more and more common, the greater part of the systems are used for heating. The presence of heat pumps on the market has highly increased over the course of the recent years. Heat pumps that enable both heating and cooling are often deployed for tempering non-residential buildings. Customers are getting used to the operation of this technology, resulting in a gain of trust towards it – even though many heat pumps perform unsatisfactorily or suboptimal in practice. Quite often, the reasons for a bad performance lie in insufficient connection to the heat source or faulty dimensioning of the heat exchanger. Additionally, heat pumps are often operated outside their design parameters, sometimes due to an overestimation of their performance during the planning period and sometimes due to incorrect use by the operator. In many cases the primary-energetic, ecological and economic potential of a heat pump is greater than the realized state.

With increasing availability of heat pumps the variety of potential low temperature heat sources and heat exchangers has grown, too. Accessing the low temperature heat sources, additional possibilities of optimization are available. While choosing a low temperature heat source, not all necessary information is always available. Innovative products like ice storages, collector fences, high performance heat collector fences, that are yet

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unknown to planners, aggravate this problem, as more information about their performance and cost-benefit ratio is missing.

In the R&D project “future:heatpump - energetic and economic evaluation of heat sources for heat pumps“ (FKZ 03ET1273A), funded by the Federal Ministry of Economic Affairs and Energy, the Institute for Building Services and Energy Design investigates the interaction between heat pumps and different low temperature heat sources as well as the corresponding heat exchangers. The central question is which heat source is the most reasonable under what circumstances with respect to energy consumption and operation costs. At the end of the project, a Pre-Check-Tool for helping planners and architects choose a suitable combination for individual cases will be available. Target figures are energy efficiency and long term cost-efficient operation of the heat pump system.

2. Project idea and motivation

2.1. First motivation – state of the art

Heat sources with a low temperature level, such as the soil or the outside air, were formerly known as "non-usable". Today, via heat pumps it is possible to make these sources accessible and to use them as a renewable energy. In addition to traditional heat sources like ground, water and air, nowadays a number of further options, such as waste water or ice storage, are available. The different systems are used to provide the heat for the evaporator in the heat pump. The systems often are used both as a heat source and heat sink for the heating and/or cooling operation.

The heat sources for heat pumps given on the market are partly very different in their functioning and performance. Until now, the systems have only been analyzed and measured in certain categories (ground-coupled, single family houses, etc.) or as individual systems without any comparison to other systems [1-3]. In certain cases, guidelines like VDI 4640 [4] or the Informationsblatt No. 43 of the BDH [5] can be referred to for selecting and dimensioning low temperature heat exchangers. Additional information about the heat exchangers are usually provided by the manufacturer in the datasheets of the products. A holistic, comparative analysis is not available.

2.2. Second motivation – Planning and energy concept

In the daily business the same planning processes take place every day. As a part of the planning the plots are determined, the building cubature, orientation and building standard are set and first calculations of the energy demand are performed. Based on this, energy concepts are evaluated and the heat supply system is chosen. Geothermal heating and cooling systems are increasingly playing a leading role and replacing the conventional heating and cooling producers such as the gas boiler. During the planning it is necessary to define how the heat pump should operate. With consideration of the boundary conditions, such as possible depth and surface boundaries, groundwater protection, etc. a heat transfer system must be found.

In this context, a simple and clear compilation of various heat transfer systems and sources is not available. This situation occurs repeatedly and the question: "Which system can be used?" Or "Which system is cost-effective?" remains open or needs further investigation. Hence the idea of our project and the implementation of this project were developed.

3. Comparative overview of heat sources and heat exchanger

In an extensive market research 24 companies have been interviewed about their products. This way, the current states of products and market have been identified.

The summarized and edited manufacturer information and the results of the market analysis are displayed in an overview matrix. 13 heat exchanger/heat pump system categories have been identified in total. They are using earth, air, and water as their heat source. The classic air-water heat pump has been added as an additional category (Fig. 1).

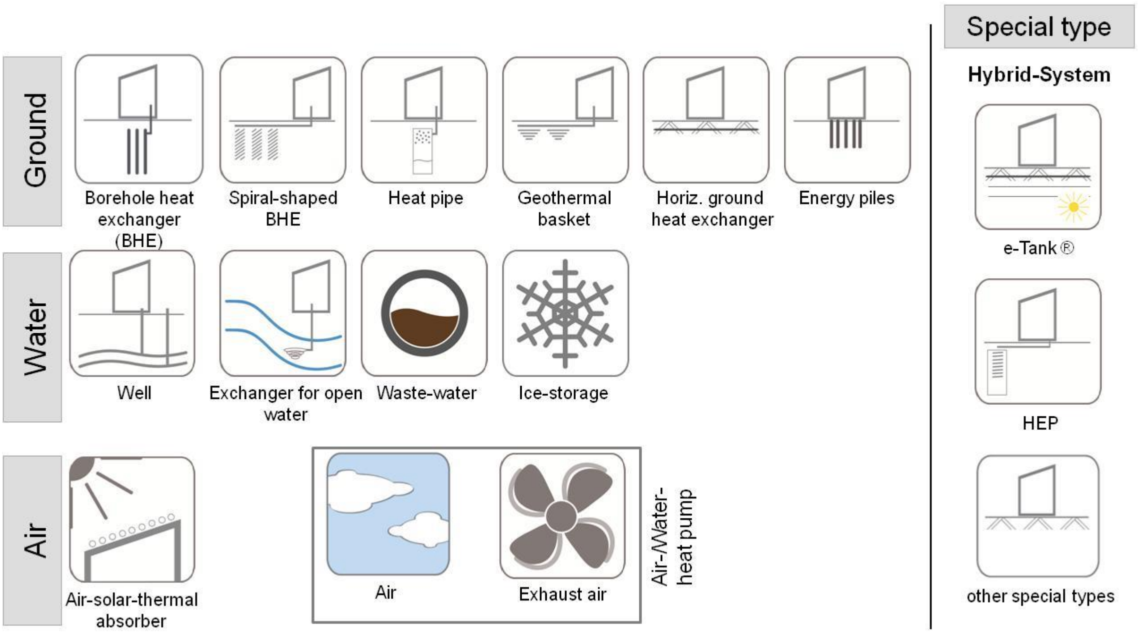

Fig. 1. Selection / categorisation of heat exchanger systems

3.1. General conditions, influential parameters and restrictions

For a reasonable choice of the low temperature heat source and the corresponding heat exchange system the general conditions, influential parameters, restrictions, and the specifications from the planning need to be taken into account.

Among other information, the following details need to be sorted out:

- climate conditions,
- energy concept of the building,
- plot area and compulsory boundary distance; possible arrangement, distances and geometry of the heat exchanger systems,
- choice of system (possibility to overbuild, free area, area required, borehole depth and / or installation depth),
- geothermal and hydrological properties of the ground (ground water and ground water flow, thermal conductivity, etc.),
- water protection area or installation depth restriction (aquifer),
- if applicable, noise protection,
- water in near distance
- other boreholes in the closer distance and possible resulting interference.

In numerous cases, almost half of the low temperature heat sources introduced are not suitable for heat pumps, because the plot areas are too small or may not be overbuilt for the regeneration of the source. Ground heat collectors or spiral collectors for instance cannot be installed below a building, as the ground needs rainfall and solar radiation for regeneration. Some systems also need additional components for the source regeneration and reliability of supply (redundant systems). An ice storage or an e-Tank® for example need an air-source heat collector or a solar thermal collector for the regeneration or loading, respectively. Waste water heat exchangers, as another example, usually necessitate a redundant heating system, in case the waste water amount is insufficient for covering the heat demand (Fig. 2).

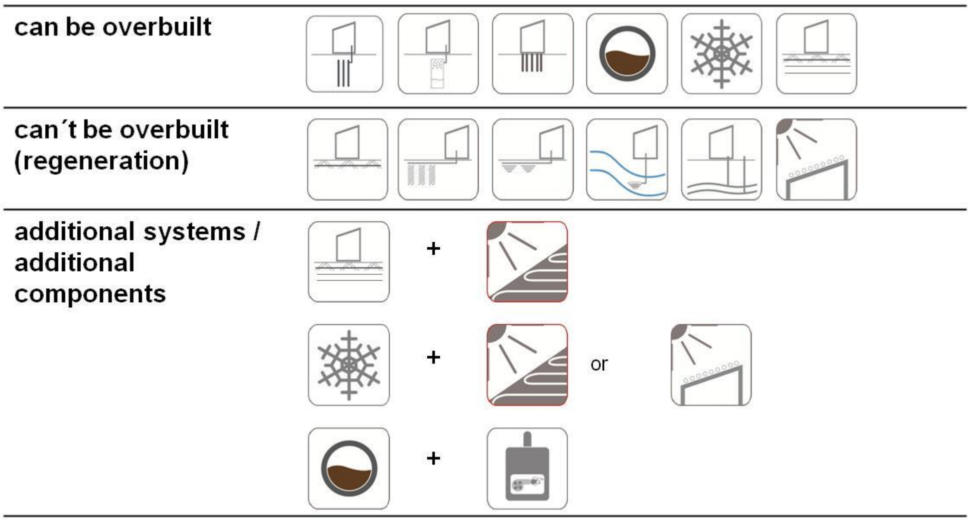

Fig. 2. *Constraints, permissibility of overbuilding, and additional systems / components*

3.2. Space requirement for heat source systems

Space requirements have to be taken in account depending on the possibility tot to overbuild the selected system. This is relevant, as the systems that can be overbuilt usually will be installed under newly constructed buildings and thus no additional space is required. On the other hand, it should be assumed that all systems shall not be overbuilt for maintenance or repair, so that the heat exchanger is accessible at all times.

Fig. 3 shows the necessary area for the particular heat sources in comparison. The diagram is based on the average parameters of the heat exchangers (heat extraction rate, distance between the heat exchanger elements, size of the heat exchanger system, etc.) given by different manufacturers. Ideal boundary conditions (geological, climatic, area, etc.) are assumed, meaning that e.g. in praxis a reduced heat extraction from the ground could be possible and therefore a larger heat exchanger area needs to be installed. The calculation of the area is performed for a residential building with a heating load of 10 kW and a heat pump with a COP of 4.0. The number of necessary heat exchangers is calculated from the assumed average parameters and the heating load. The calculated necessary area includes the distances between the heat exchangers. (Table 1)

The required distances between the systems, to the plot boundary and to already existing pipes are already taken into account. Thus, the areas indicated in Fig. 3 are a "minimum space requirement" for the specific heat exchanger systems, neglecting their possibility to be overbuilt. In case of new buildings, the systems marked with *) could be arranged below the structure. In case of reduced heat extraction from the ground, additional heat exchangers and additional area are required.

The analysis shows that near-surface systems with an installation depth < 10 m need the hugest area. These systems are horizontal ground heat exchanger with a noteworthy mutual horizontal impact. To minimise this mutual impact and to avoid glaciation, the distances between the singular elements and pipes need to be taken into account.

Table 1. Assumptions for the determination of the necessary area

heat exchanger system	diameter heat exchanger [m]	distance between heat exchanger [m]	assumed heat exctraction [W/m, W/Stk, W/m²]	number of	comment	total space requirement [m²]
BHE	0.18	6	100	1	BHE 100 m	30.0
spiral-shaped BHE	0.5	3	1 500	5	-	48.1
geothermal basket	2.4	4	2 000	4	-	128.7
horzontal ground heat exchanger	-	-	40	-	-	187.5
energy pile	0.5	5	85	6	pile 15 m	142.5
waste-water	6	-	1 800	1	-	6.0
exchanger for open water	1.1	4	15 000	1	-	20.4
well (groundwater)		30	each 1 production and injection well			30.0
air-solar-thermal absorber	-	-	500	-	-	15.0
ice-storage	2.7	2	10 000	1	-	17.3
air-water heat pump	-	-	10 000	1	only equipment: H/B/T [mm] 1045 / 1490 / 593	0.88

assumption:	heating power building	10 kW
	COP HP	4
	heat extraction source	7.5 kW

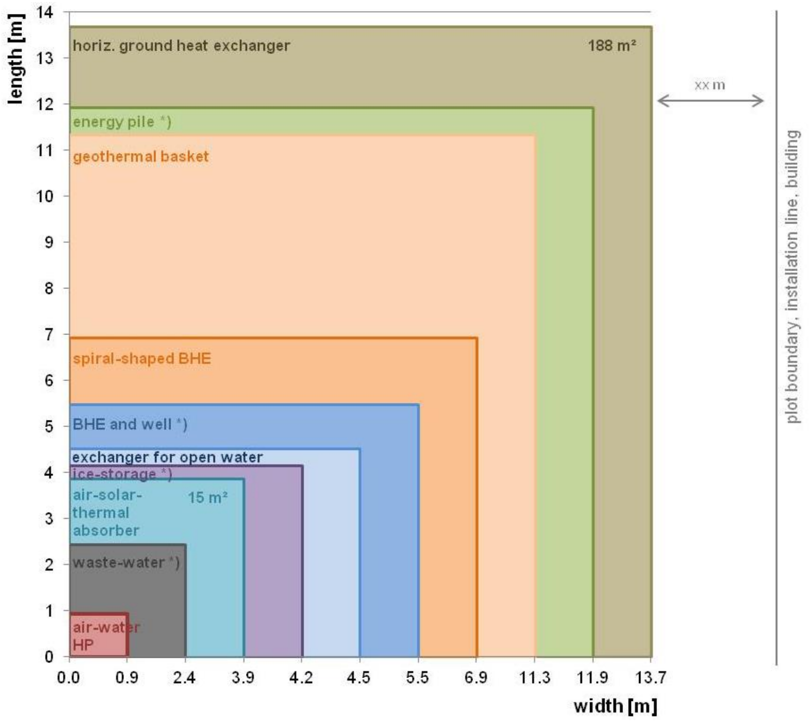

Fig. 3. Necessary area for low temperature heat sources scaled to 10 kW heating power (assuming ideal geological conditions); *) overbuild, could be installed below the building

3.3. Manufacturer survey and summary of systems

The surveyed information especially contains:

- general information about the materials in use and the structure of the heat exchanger as well as the planned heat sources and special requirements,
- statements regarding the dimensioning and installation of the heat exchangers and the appropriate heat fluid,
- special features during the operation of the heat exchanger and predicted heating or cooling power, e.g. to the earth based on different soil qualities and the temperature of flow and return,

- designed applications (single-family houses, multi-family houses, offices, new/retrofitted buildings, heating, hot water supply, cooling, etc.) of the technology,
- investments for material and installation costs,
- legal boundaries and regulations for installation, design commandments, and if applicable design and dimensioning instructions

The research and the information in Table 2 imply that the maximum heat injection and extraction depends on the choice of the heat exchanger. Quality and composition of the soil need to be known. The specifications in the table consist of average values in Germany.

Table 2. Overview heat exchanger systems (average values of manufacturer statements)

heat exchanger system	source	dimension heat exchanger	installation depth	heat extraction and injection power	boundary conditions
BHE	ground	Ø 75 - 180 mm	> 100 m	30 - 100 W/m	meet the distance between BHE attend the regulations / boundary conditions subject to approval
spiral-shaped BHE	ground (solar radiation, rainfall)	Ø ~500 mm	bis 15 m	bis 1.500 W/BHE	can not be overbuild outside deep-rooted trees
heat pipe	ground	Ø 60 cm	bis 275 m		antifreeze fluid not necessary (u.a. CO_2-tube) brine circuit not necessar only for heating mode subject to approval
geothermal basket	ground (solar radiation, rainfall)	Ø 1,4 - 4.0 m	1 - 4 m	700 - 2.000 W/basket	can not be overbuild space-saving, but facing hight temperature fluctuations
horzontal ground heat exchanger	ground (solar radiation, rainfall)	no space requirement, distance between tubes	1,2 - 3,0 m	10 - 40 W/m²	can not be overbuild high space requirement
energy pile	ground	Ø up to 0,6 m	10 - 30 m	40 - 85 W/m	use synergy effects if static requirements are necessary sufficent load capacity of the piles must be ensured (no temperatures <5 ° C)
waste-water	waste-water	1,0 m x 0,6 m	sewer	bis 1.800 W/m²	customers with high heat demand (> 50 kW) dry weather flow min. 10 - 15 l / s connection max. 100 - 500 m redundant system required subject to approval by sewage plant
exchanger for open water	water	height 1,1 m Ø 1,1 m	in the water 3 - 30 m depth	6 - 15 kW/unit (extraction) 6 - 26 kW/unit (injection)	possibly subject to approval in public waters
well (groundwater)	groundwater		10 - 200 m	500 - 600 W/m³/h	observe groundwater quality: analysis of the groundwater for pH, iron, manganese (risk of dangling) Pump test required: determination of eligibility / fertility subject to approval
air-solar-thermal absorber	air (solar radiation)	2,1 - 4,0 m x 1,0 - 1,2 m	roof mounted		no drilling, no environmental risk, no groundwater protection, e.g. in combination with ice-storage as a regeneration system or as a single system
ice-storage	ground (solar radiation, rainfall)	Ø up to 2,7 m	up to 10 m	4 - 18 kW (extraction) 3,5 - 7 kW (injection)	high heat demand -> high store size additional system required for regeneration (absorber, solar thermal energy) also cooling in the summer case possible
air-water heat pump	air				visual criteria for installation site taking into consideration of sound insulation air intake or outlet side freely accessible

4. The Pre-Check-Tool

The Pre-Check-Tool designed during this project will be made public online at the end of the project time. Based on the included heat sources and heat exchangers the tool enables planners and architects to make a preselection of suitable low temperature heat sources and heat exchanger systems for individual projects. In addition to the preselection, the tool offers a rough dimensioning of the heat exchanger.

4.1. Structure and method

In the beginning the structure and method for the tool’s development have been settled. The tool consists of several blocks, as illustrated in Fig.4. To record and model all interfaces, the blocks are initially implemented in

MS Excel. In a second step the structural composition is complemented by contents of literature and standards. Various simulation results of the analysed heat sources and building types are added in a third step. The simulation results especially extend the options of pre-dimensioning of the heat exchangers. The calculation of the heat pump's performance and an estimation of the necessary power, especially regarding the low temperature heat source, are executed within the Pre-Check-Tool.

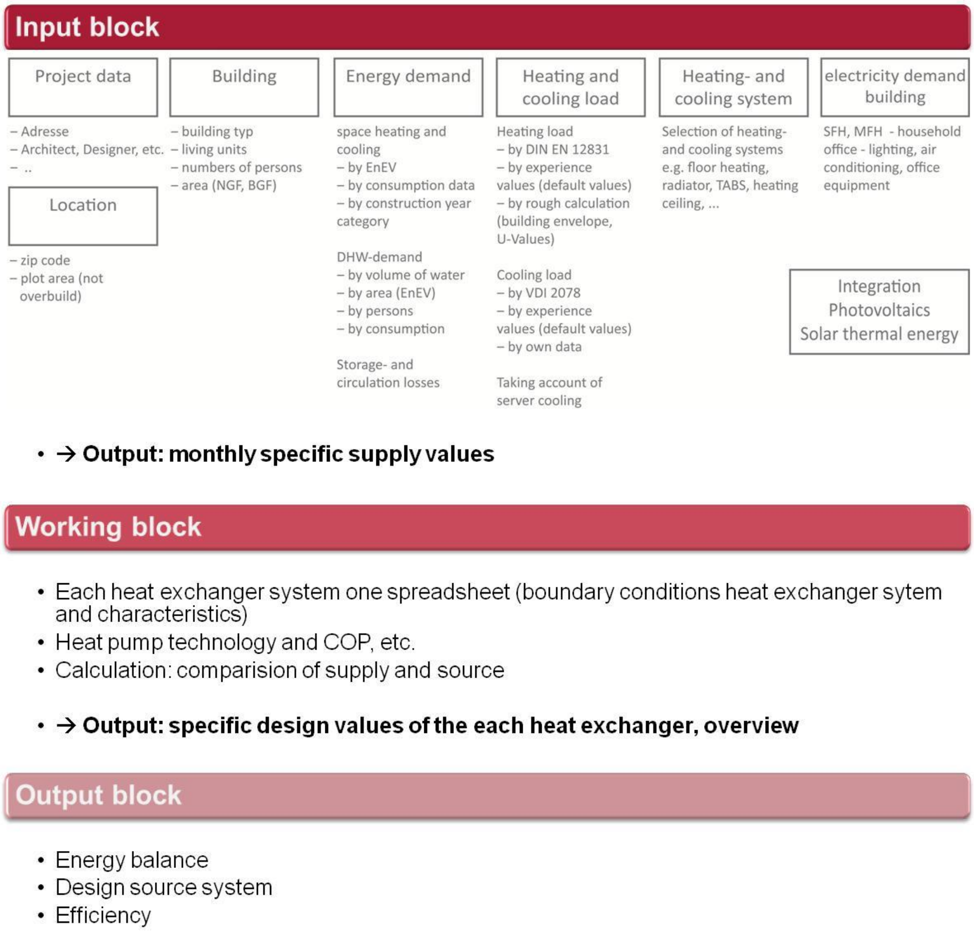

Fig. 4. Schematic structure of the Pre-Check-Tool (working version)

4.2. Control interface of the Pre-Check-Tool

Feeding input to the Pre-Check-Tool starts with entering the overall situation and general conditions of the project. Via a user-friendly interface the operation is to be eased and the entry of faulty input avoided. The user chooses the description of the project from a set of predefined options and makes fundamental statements like the building type and the thermal building standard. Further specifications like the plot area and the energy demand of the building can be entered via input fields, if they are known. The user can make assumptions regarding the heating and cooling system and define additional requirements. Unspecified information is automatically supplemented with standard values by the program. (Fig. 5).

On the basis of the analysed systems and its variations the programme calculates a preselection of suitable heat sources for the project. Ecological (CO_2-emissions, primary energy consumption) and economical (investments, operation costs) parameter are being displayed and compared to conventional heating and cooling techniques. Additionally, the Pre-Check-Tool informs the user about important side conditions of the respective system variant like acoustic protection for air-to-water heat pumps or required pump tests for the utilisation of ground water. The indication to a cooling option is also displayed at this point.

Fig. 5. Pre-Check-Tool, current state and graphic user interface in MS Excel

5. Conclusions and outlook

Heat pump technology will play an important role in future heating and cooling systems. To fully and efficiently use their potential, the selection of the corresponding low temperature heat source and heat exchanger for each project is of particular importance. The Pre-Check-Tool introduced in the course of this project serves as a multifunctional and flexible tool for combining theoretical assumptions, numerous system simulations, and measured data to make well-reasoned decisions regarding the optimal system design. The programme enables the user to conduct a preselection and rough dimensioning of adequate heat exchangers for utilising low temperature heat sources while keeping special requirements of the particular systems in mind. It will contribute to the efficient use of heat pumps.

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All indicated characteristics, costs and boundary conditions are based on data provided by manufacturers and surveyed companies.