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HEATING AND COOLING WITH THE EXISTING HEATING SYSTEM
A contribution to the optimization of existing heating systems in residential buildings over the entire year

Manuel Kornmacher[1], André Kremonke[1],

[1] Technical University of Dresden, Institute of Power Engineering, Chair of Building Energy Systems and Heat Supply

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Abstract:

Within the building sector, the greatest potential for reducing greenhouse gas emissions lies in existing residential buildings. Furthermore, many of these buildings must be protected from overheating during the summer months. A common solution approach for both problems is being tested as part of the KUEHASystem project in a field test facility in Leipzig with 36 residential units.

This approach primarily relies on heat pump technologies, which can provide both heating and cooling. Synergy effects arise particularly in system configurations in conjunction with geothermal probes. Radiators are used for room-side heat transfer in both heating and cooling modes. In particular, the temperature control effect in summer should be evaluated. For comparison, approximately 50% of the comfort rooms on the standard floors (children's rooms, living rooms and bedrooms) were equipped with fan-assisted radiators. In the subsequently converted attic, only fan-supported heating surfaces were used. Replacing the heating surfaces is comparatively cost-effective and allows for a significant reduction in system temperatures when heating and higher cooling outputs in summer.

As part of detailed monitoring, all energy flows and relevant temperatures from the central heating and cooling system and all residential unitsare recorded to evaluate the system behavior and the room air conditions.

In addition to testing and validating the system solution, the investigations on the object provide detailed results with regard to the control interaction of bi- or multi-valent systems including renewable energy sources.

1. Introduction/Motivation

There are currently two major challenges in the German building sector. On the one hand, the aim is to reduce the greenhouse gas emissions resulting and caused by the use of the building and, on the other hand, to prevent living spaces from overheating during the summer heat period.

Climate change affects buildings and their utilisation in various ways. The higher temperatures lead to an increase in heat stress among people living and working in the buildings. This in turn triggers health symptoms such as circulatory problems, exhaustion and reduced performance. In addition, the overall mortality rate increases due to heat stroke, dehydration and cardiovascular diseases [1]. This effect is exacerbated by the fact that the cooling phase is shortened overnight and the buildings cannot cool down sufficiently [2]. In urban areas, the effect of heat is further intensified, as heat is additionally stored due to the narrow development and the high proportion of sealed areas [2]. The phenomenon of heat or heat islands arises [3]. Climatic changes are leading to a reduction in heating demand and increase in cooling requirements [2]. However, most existing residential buildings in Germany are not equipped with options for cooling rooms in summer. For these existing buildings, this means that solutions are needed that enable room cooling without jeopardizing climate targets, including climate neutrality in 2045 [2]. Retrofitting with conventional air conditioning systems, for example, means that air conditioning rooms leads to the production of more CO_2. This shows that new concepts are needed for cooling buildings. Systems engineering approaches that are currently being pursued are based primarily on surface heating and cooling systems, which can only be implemented with great effort and high costs in existing buildings. Although structural measures such as the insulation of opaque components, help to reducing heating energy requirements and can also reduce the CO_2 emissions caused by the operation of the heating system, the thermal situation indoors is exacerbated during the heating periods, as the heated rooms can only cool down slowly. Another approach utilizes the existing free heating surfaces for cooling. In principle, this means that a cost-effective and energy-efficient transfer of cooling energy can be achieved in existing residential buildings. In this context, the year-round consideration of heating systems, including the cooling period in summer, is becoming increasingly important.

The KUEHASystem project focuses on optimizing existing heating systems in residential buildings throughout the year, with a special focus on the summer cooling periods. The goal is to develop a system solution that enables efficient system operation all year round, taking into account variable objectives such as economic efficiency, ecological footprint or comfort.

Theoretical studies, simulations and field tests are conducted to validate the efficiency and effectiveness of the proposed approaches and the system controller. The results aim to provide new insights into the area of building heating and cooling, as well as practical guidelines for the planning and optimization of heating systems in existing residential buildings. With this holistic approach, the studies contribute to reducing CO_2-emissions and increasing sustainability in the residential building sector.

2. Initial situation

The possibility of room cooling via free heating surfaces has already been subjected to a comparative evaluation based on numerical studies in [4], [5] and a laboratory-like field test [6], with the result being a promising prospect. As part of the KUEHA[1] project, initial small-scale implementations were carried out to estimate the cooling potential (see e.g. [7]). The room temperature reduction potential identified was further confirmed in [8] through laboratory studies and additional simulations.

As a prerequisite for broad practical implementation, the key research areas outlined in Fig. 1 were addressed in the KUEHA project on the basis of field tests and laboratory studies, as well as analytical and numerical considerations (see [9]).

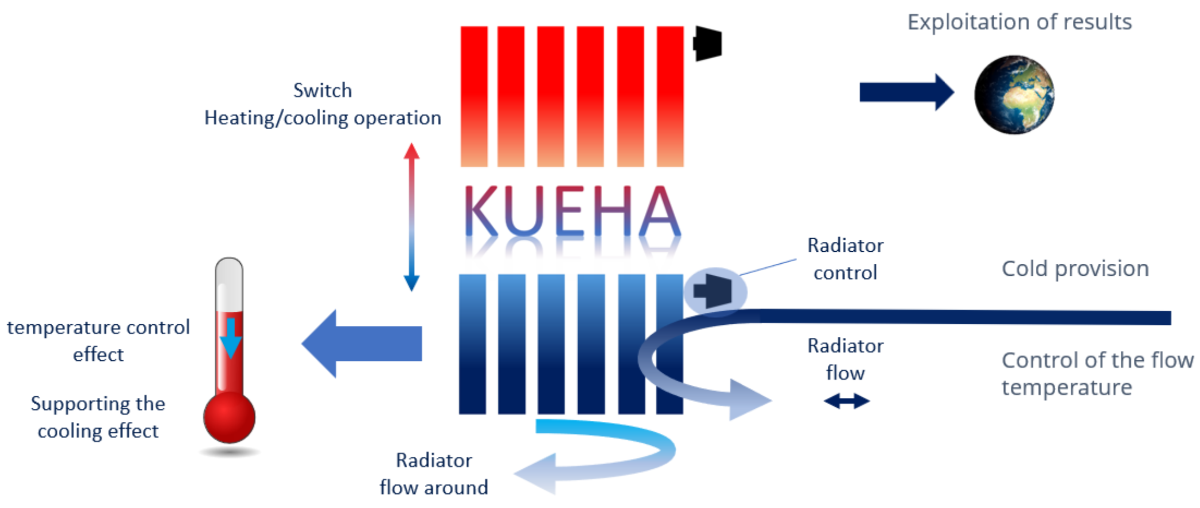

Figure 1: Key research areas worked on in the KUEHA project [8]

[1] EnOB: KUEHA - Testing and demonstration of a novel system solution for summer room cooling with particular consideration of energy efficiency and practical suitability (duration: 06/2017 – 05/2020)

As an example, Fig. 2 presents selected results for radiator mass flow. It was necessary to evaluate whether a thermally induced short-circuit flow could occur during cooling, which would counteract the full-surface cooling of the heating surface. This effect is particularly to be expected with older multi-layer heating surfaces with parallel flow plates.

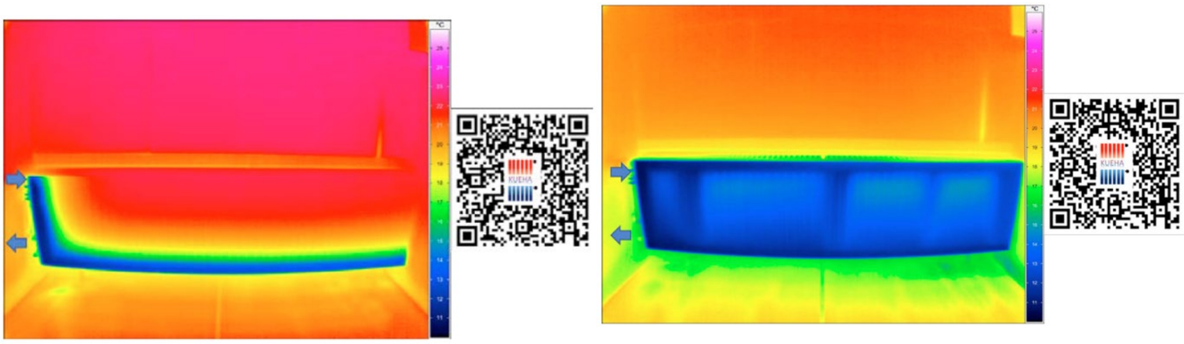

Figure 2: Result of the flow through the heating surface in the cooling case with a low mass flow in a multi-layer radiator - left: plates with parallel flow (short-circuit flow), right: plates with serial flow [8]

For existing residential buildings, [7] assessed the problem of summer overheating and the potential of cooling via free heating surfaces as a problem solver.

The current co-operation project KUEHA*System*[2] aims to develop and test a system solution for broad practical application. This solution was implemented for the first time on a significant scale by WOGETRA[3] in an existing residential building. The field test object, hereinafter referred to as MFH-WOGETRA-2, is located in the north of Leipzig, in a densely built-up mixed area of single- and multi-family houses as well as several allotment gardens. The building was built in 1962 and corresponds to the construction standard of the L4 IW/58 residential building series, which was typical at the time. The property, which was renovated in 1992, comprises 36 residential units. These are divided into four staircases, four standard floors and the attic, which was opened up in 2006. The total living space is approx. 2,450 m². As part of the renovation, the thermal insulation was improved and the stove heating was replaced by a central heating system. The existing system, which was in operation until 2023, essentially consisted of two 70 kW oil boiler systems and a 500 l hot water tank.
This building type, including the renovation measure and the existing heating system, represents a large proportion of the existing residential buildings in East Germany, so that the results from the research project and the field test investigations are scalable on a large scale. It can also be transferred to other building types. To validate the system solution, particularly detailed monitoring was set up in the field test object. In addition to recording all energy flows from the central heating and cooling system, the thermal situation in all residential units is also recorded at a minute-by-minute resolution.

3. Implementation and research methodology

The essential steps for implementing the system solution at the MFH-Wogetra-2 field test object were realised between June and October 2023. The work was divided into three sub-areas.
First, the probe field was installed (16 double U-tube probes each 100 m long) as an energy source and energy sink as shown in Fig. 3. The energy field was set up on the open space in front of the east side of the building.

[2] Joint project: KUEHASystem - Year-round overall system optimization to reduce CO_2-emissions from existing heating systems - Demonstration of a system solution for heating and cooling; Sub-project: System analysis
[3] Wohnungsgenossenschaft Transport eG Leipzig www.wogetra.de

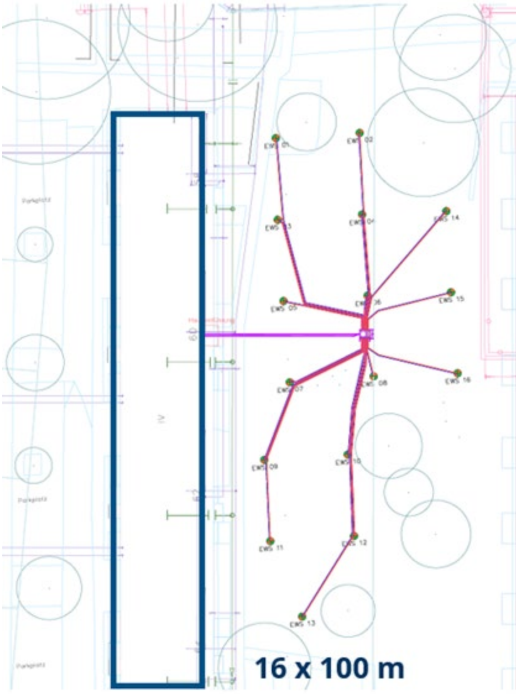

Figure 3: Concept of the probe field [10]

The second phase of the implementation took place in the area of the former heating centre and in the area of a former tenant's basement, which had to be additionally adapted for buffer storage due to the limited space in the actual heating centre and the abundance of technology. The system diagram shown in Fig. 4, which is based on previously carried out simulation calculations, was implemented in both rooms.

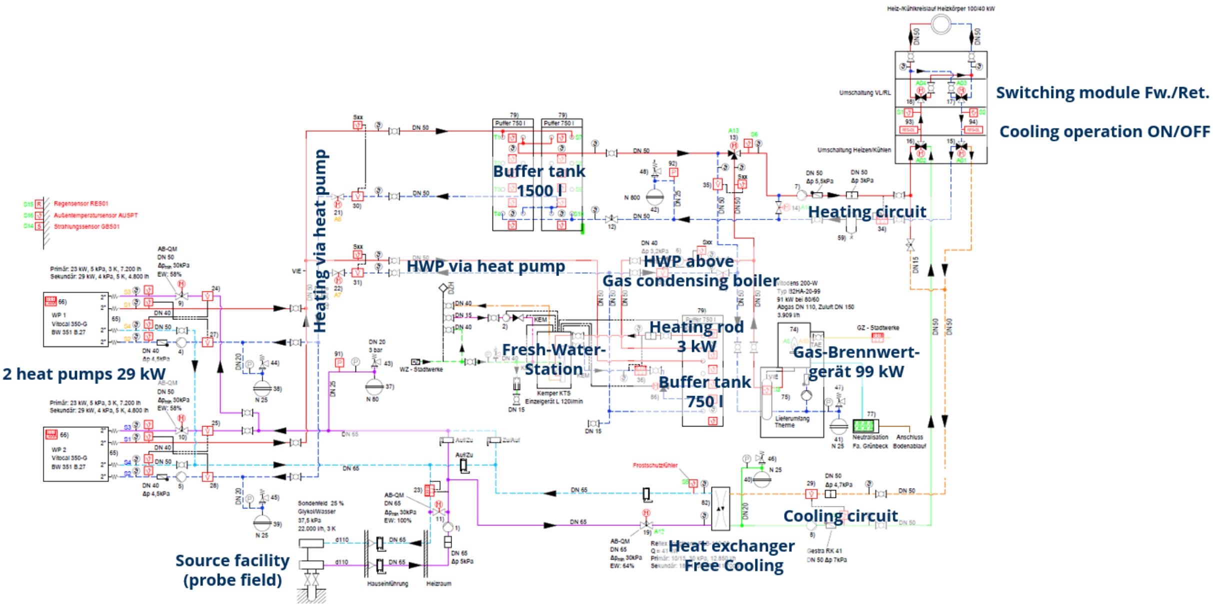

Figure 4: System diagram of the heat and cold supply system

Due to the complexity of the system and the limited space, detailed 3D planning of the energy centre (see Fig. 5) was necessary before the actual implementation.

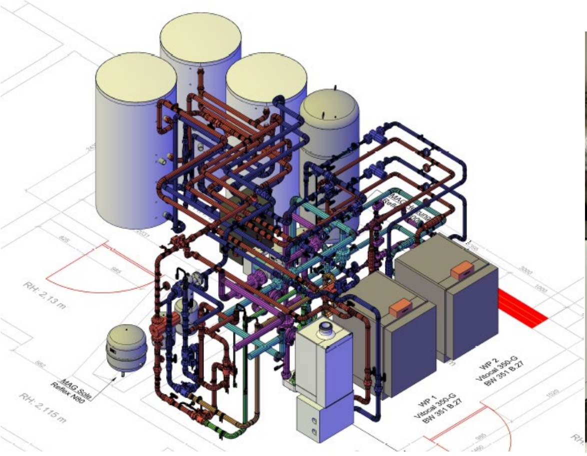

Figure 5: 3D planning energy center

Figure 6: Boiler room view after implementation

Fig. 6 shows the completed energy supply system. This shows the two stages of the heat pump system as well as the system controller in the foreground and the peak load boiler on the left edge of the picture.
The final implementation measure was to replace the heating surfaces in the apartments by October 2023. In addition to the thermally-related heating surface replacement, the thermostat heads on each heating surface were replaced.
Two monitoring systems are used for the investigations in the field test object. The focus of one system is on the real-time recording and representation of the system states and also enables intervention in the regulation and control of the central heating and cooling provision. The second monitoring system enables near real-time visualization of the temporal system behaviour and includes options for evaluating system states through data aggregation. Both systems complement each other and serve as a basis for further development into an overall system in the context of the system controller.
In addition to recording data values in the area of the energy supply system, the room temperature and humidity as well as the air pressure are recorded in the entire living area of the 36 residential units. Additionally, a heat/cooling meter has been installed in front of each residential unit to record the energy flows. An individual room control system was also installed in a top-floor apartment. This system makes it possible to record and evaluate the valve lifts of the thermostat valves and thus draw conclusions about the supply status of the entire system.
Due to this extensive measurement recording, system malfunction can be quickly detected and corrected and research questions can be answered in detail and comprehensively.

4. Operating experiences and monitoring results from the heating season

On January 1, 2024, after a lengthy commissioning phase, systematic measurement data recording began. The monitoring focuses on probe field temperatures, efficient heat pump operation, minimizing the operating times of the gas condensing boiler, ensuring thermal comfort during the heating season, and evaluating the implemented option for summer cooling. In this regard, Fig. 7 shows the development of the monthly performance figures (MAZ) of the heat pump system. This increases from 4.1 in January to 4.6 in April. Taking the auxiliary energy into account, the MAZ is in the range between 3.3 and 3.5. When it comes to auxiliary energy, priority is given to the power consumption of the brine circulation pump, the heating circuit pump, the circulation pumps on the condensers and the power consumption of the control system.
The fact that the MAZ does not increase continuously taking into account the auxiliary energy is primarily due to the ratio of the amount of heat provided to the required electricity consumption in the area of auxiliary energy.

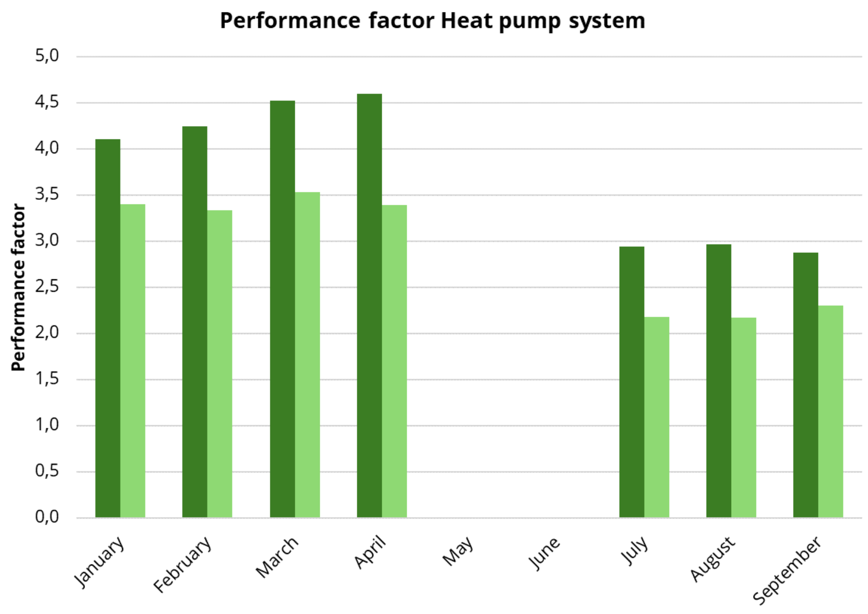

Figure 7: Performance figures of the heat pump system with and without taking the auxiliary energy consumption into account

5. Initial experiences and monitoring results from the cooling period

Since June 19, 2024, the usage units in the MFH-Wogetra-2 field test object have been continuously controlled via the existing free heating surfaces. The dampened outside temperature is evaluated to enable or disable cooling operation. If the threshold value of 22 °C is exceeded once, the release occurs and is maintained for 24 hours. If the threshold value is exceeded again during this time, the maintenance of the function is extended for a further 24 hours from the time the exceedance occurred. If the threshold value is no longer exceeded during this period, the cooling function is switched off. Figure 8 shows the course of the dampened outside temperature and the status of the cooling operation.

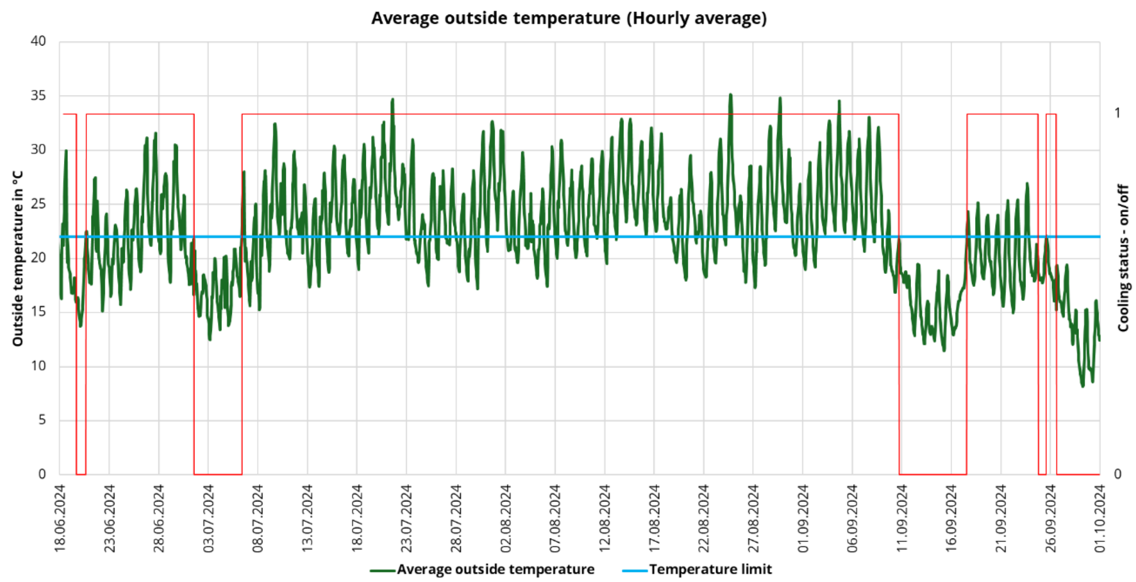

Abbildung 8: Average outside temperature with status cooling mode ON/OFF

Fig. 9 shows that when the cooling function is activated, an average of between 10 kW and 15 kW cooling capacity is available, regardless of the time of day. On average, between 200 kWh and 350 kWh of heat can be extracted from the apartments per day and used to regenerate the probe field.

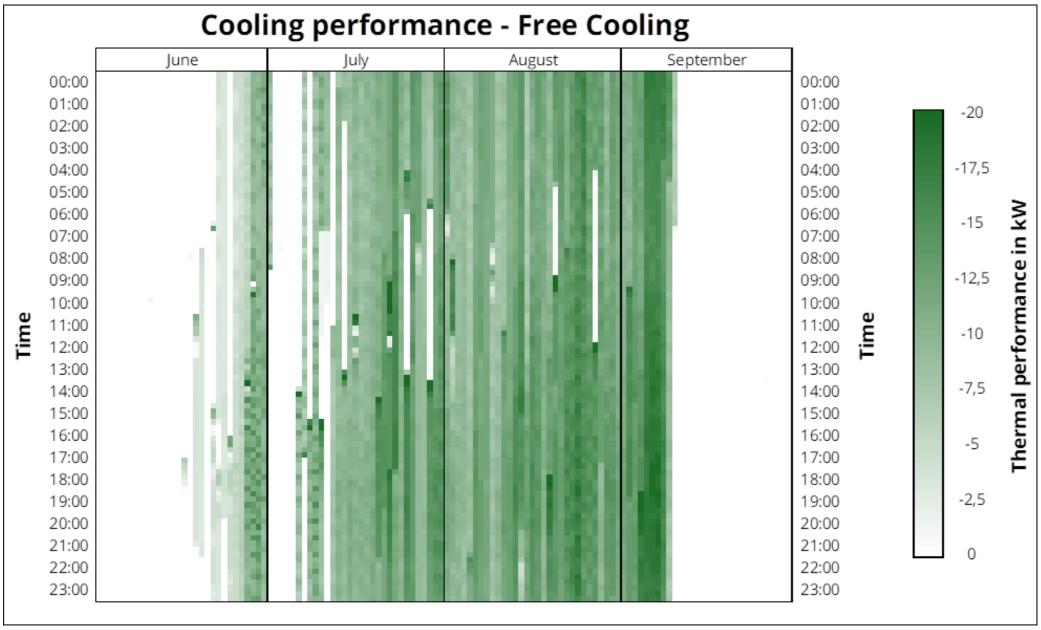

Abbildung 9: Carpet-Plot for cooling performance

Fig. 10 shows that during the summer months, the entire extraction energy requirement for hot water preparation can be covered by free cooling and at the same time the soil is regenerated.

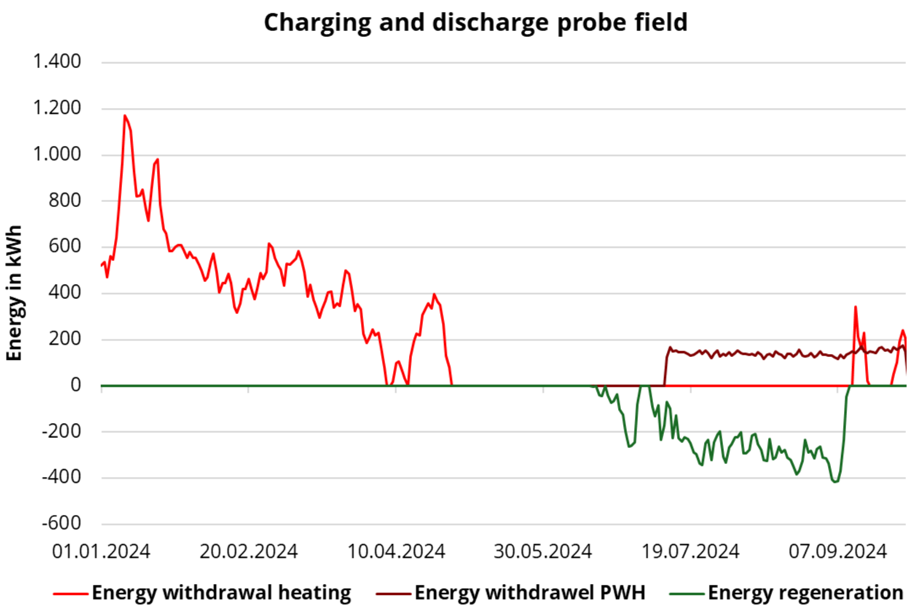

Figure 10: Loading and unloading of the energy field over the course of the year

In order to be able to assess the effect of cooling via free heating surfaces, the daily maximum of the hourly average room temperature was shown in Fig. 11 over the daily average outside temperature WITH and WITHOUT cooling for the comfort rooms (“living”, “sleeping”, “children”) an attic apartment was evaluated. When cooling via free heating surfaces, a significant reduction in room temperatures is observed, even at higher average outside temperatures, compared to the uncooled comparison case.

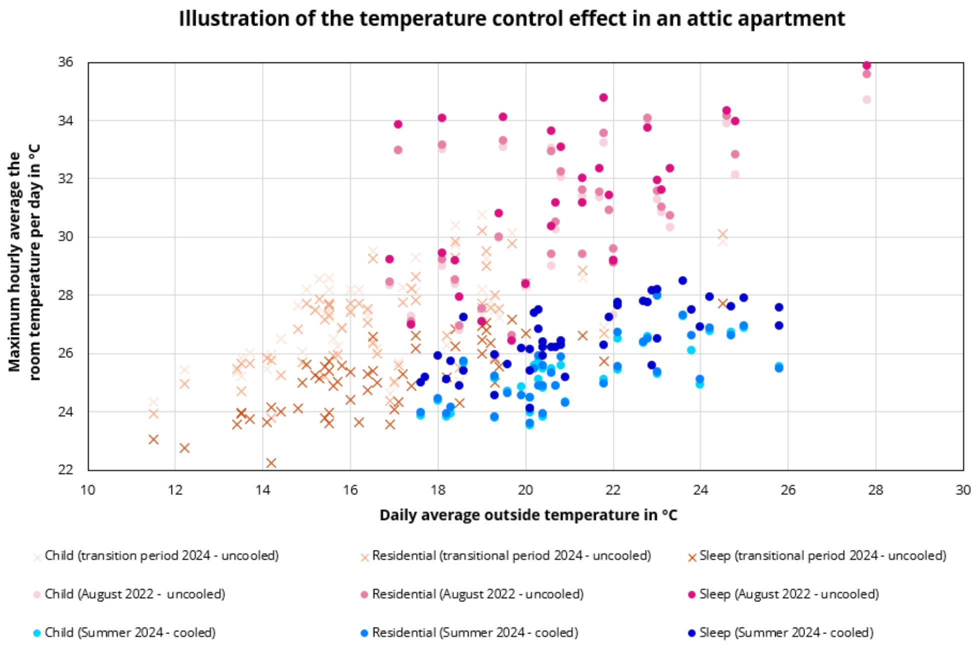

Figure 11: Maximum hourly average room temperature versus the daily average outside temperature to illustrate the temperature control effect in an attic apartment

When cooling via free heating surfaces, a significant reduction in room temperatures can be seen, even at higher average outside temperatures.

Fig. 12 gives an overview of the efficiency and costs of cooling via free heating surfaces. For the evaluation period from June 19, 2024 to September 30, 2024, the diagram shows the amount of heat extracted and the electricity required for this as well as the total operating costs based on an assumed purchase price for electrical energy of €0.30/kWh.

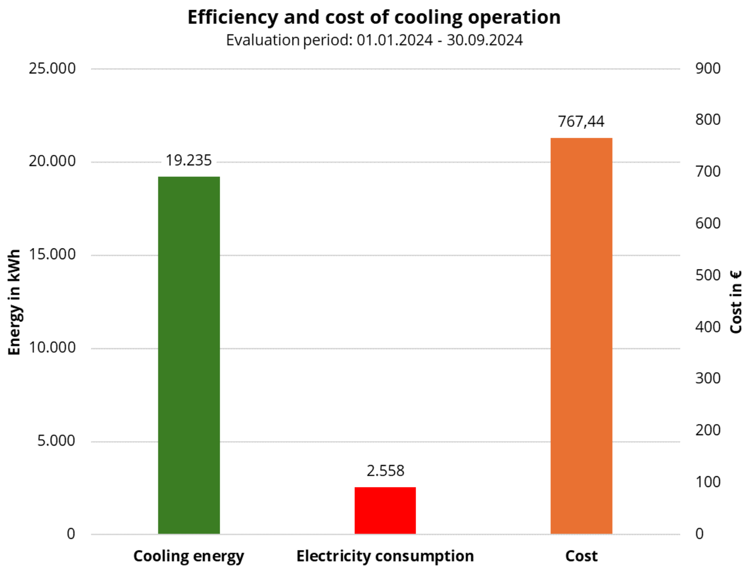

Abbildung 12: Auswertung der Effizienz und der Kosten des Kühlbetriebs

The evaluation shows that an average performance factor of 7.5 is achieved. Therefore, the costs of room cooling are therefore around €0.04/kWh. However, if you look at the overall balance, it can be assumed that the costs are significantly lower because the amount of heat extracted from the building is transferred to the probe field, regenerating it and thus making heating and hot water preparation more efficient.

6. Summary and outlook

The studies show that by using outdoor heating surfaces in summer, a noticeable reduction in room temperatures can be achieved. Additionally, the cooling contributes to the regeneration of the probe field, which increases the efficiency of the heat pump systems in heating mode. The results from the 2023/2024 heating season and the 2024 cooling season demonstrate that the system works reliably and is highly accepted by users. The simulations conducted and the field tests are intended to serve as the basis for the development of a system controller that optimizes the entire system taking into account economic, ecological and comfort criteria. The outcomes of this project are intended to continue to provide practical guidelines for the planning and optimization of heating systems in existing residential buildings and to contribute to reducing CO_2-emissions and increasing sustainability in the building sector.

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