Identification of Temperature Reduction Potentials in Heating Circuits based on Measurements

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Abstract

This paper aims to find the potential for decreasing system temperatures of the district heating network at the University of Kassel. The district heating network as well as many of the supplied buildings was constructed in the 1980s. Embedded in the development of an overall concept to decarbonize the heat supply on the university's campus the Department of Building Services is evolving a methodology to estimate the contribution of supply temperature reduction. This research involves the systematically investigation of the highest possible supply temperature decrease without impairing the buildings' heat supply. The methodology includes three steps: 1. Identification of the critical buildings; 2. Identification of the critical heating circuits in the critical buildings; 3. Identification of the critical rooms in the critical heating circuits.

Keywords: heat supply, district heating, non-residential building, supply temperature reduction, heating circuits, heating control, heating-up trial, temperature measurement

1. Introduction

The research project "EnEff:Stadt/Campus: Campus Kassel 2030 - Concepts and Measures for the Accelerated Implementation of the Energy Transition in Higher Education" aims the development of an overall concept for the reduction of greenhouse gas emissions (GHG) regarding the heat supply at Kassel University. A district heating network built in the 1980s supplies 17 non-residential and 3 residential buildings at Campus "Holländischer Platz Süd" with heat. The district heating network is connected to the city network. It was designed to operate on a temperature level of 130 °C (supply temperature) and 75 °C (return temperature). The evaluation of measurement data shows that the effective operating temperature level is 105 °C/65 °C. Due to the high system temperatures, a potential to decrease the resulting distribution losses and greenhouse gas emissions by lowering the supply temperature exists. There is no reliable information of how far the heating network temperature can be reduced without impairing the heat supply of the buildings. The paper aims to give an insight into the approach to quantify the possible reduction of the supply temperatures in non-residential buildings based on measurements.

In the determination of reduced supply temperatures in heating systems studies are mainly related to residential buildings. Benakopoulos et al. (2022) present "a strategy for low-temperature operating of a radiator system by calculating the minimum supply temperature required in the system […] by using data from electronic heat cost allocators" for the study of a multi-family apartment building. However, they do not focus on specific heating circuits in different buildings. In the course of optimizing radiator heating systems in residential buildings, Jagnow et al. (2006) deal with the question of how a new temperature level can be identified and realized. For more complex non-residential buildings, Oltmanns (2021) developed a detailed dynamic simulation model of the energy system of "Campus Lichtwiese" at TU Darmstadt to determine the reduction potential of the district heating network among other aspects. The approach presented in this paper focuses on the use of measurement data.

1.1. System description

To examine the temperature reduction potentials, those buildings and those heating circuits are to be identified that are expected to be critical to decreased supply temperatures. "Critical" refers to the ensuring of heat supply for the connected buildings. Thus, the heat load of the buildings and heating circuits have to be quantified. The design outdoor temperature (T_A^*) is an important criterion for this examination. In Kassel, the design outdoor temperature is -12 °C. The analysis takes place in three steps as shown in Fig. 1.

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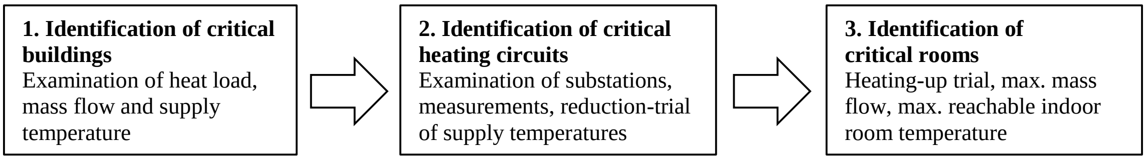

Fig. 1: systematic structure of the overall approach

The building-level (step 1) analyzes buildings on the primary (network) side. It focusses on the heat exchangers and tries to detect buildings, which might be critical in relation to a system temperature reduction and should be prioritized for further examination. It is described in more detail in a separate conference paper entitled: "Transformation of a University Campus: Comparison of Ranking Methods for Temperature Reduction from Network and Building Perspective" (Bergsträßer, Neusüß et al., 2022).

The presented paper gives an insight into the work of heating circuit level (step 2) and room level (step 3). The work focuses on the secondary side of the heating network. On heating circuit level, measurement data from different heating circuits are analyzed concerning the potential of temperature reduction. A decrease of the supply temperature during a reduction trial in several heating circuits should identify errors or insufficient heating regulation and critical rooms. Furthermore, a promising approach is the analysis of measured temperatures in rooms from heating circuits during a heating-up trial on the room level. Step 2 and 3 are still in progress.

1.2. Approach

The non-residential buildings on the university's campus supplied by the heating network are equipped with diverse fluid heating circuits of different types. Those types include static circuits, using radiators as transfer systems, dynamic circuits to heat the supply air of ventilation systems and warm water circuits, and panel heating systems using floor heating or radiant ceiling panels as transfer systems. The circuits require different supply temperatures (Sangi et al., 2015). Most of the existing heating systems at the university are in its original state from the 1980s and run on high temperatures, exposed from interviews with technical staff, from documents archived by the building department and from little measurement data of the substations. There are sparse information in relation to the designed system temperatures for the secondary side. Fig. 2 displays a simplified hydraulic diagram of a typical substation at Kassel University describing the primary and secondary side.

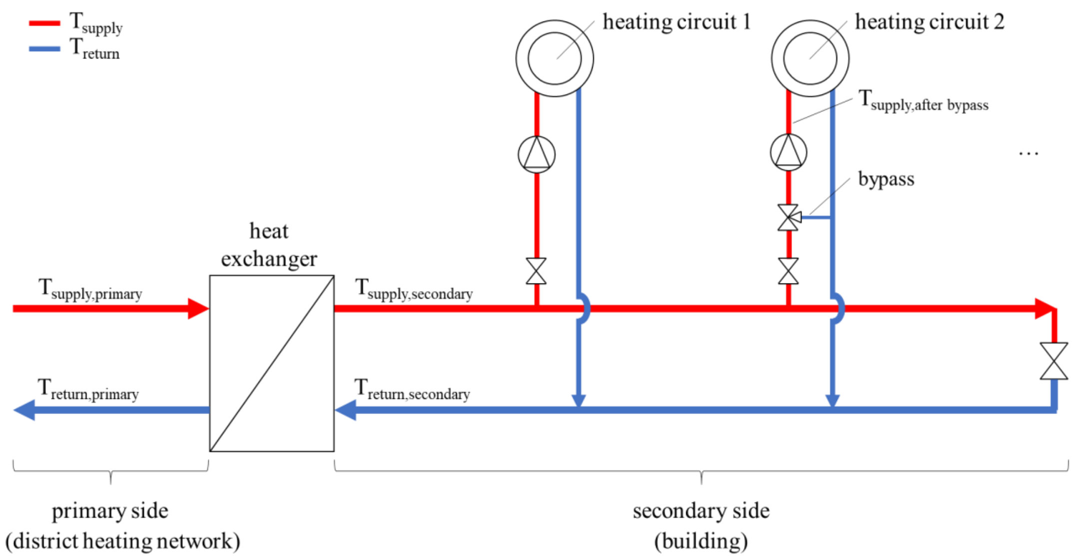

Fig. 2: Simplified hydraulic diagram of a typical substation at Kassel University

The design temperatures for the heating circuits of only seven buildings, built in 1985 to 1988, are available. In these cases, the supply/return temperature for T_A^* are 90/70 °C. It is not clear, which system temperatures are currently required in the buildings because mostly there exist no measurement points on the secondary side of the substations. It is necessary to analyze the needed supply temperatures and heat loads of heating circuits for the design outdoor temperature of -12 °C. Therefore, measurements must be taken. They are described in the following chapter.

2. Heating Circuits

As mentioned before, the buildings at Kassel University have different heating systems like static, dynamic and panel heating. Within the framework of CampusKassel2030, five buildings with different main usages were examined. Tab. 1 provides an overview of these buildings that includes the main use, the installed heating circuits and photos taken by the authors. The numbers show the amount of the measured heating circuits. The numbers in parentheses display the total amount of the existing heating circuits in the building.

Tab. 1: Overview of the measured buildings

Picture of the building (pictures taken by the authors)	**Building function/ description**	**Number of static heating circuits**	**Number of dynamic heating circuits**	**Number of panel heating circuits**
	Office and institute building with a cafeteria	2 (2)	2 (2)	1 (1)
	Lecture hall	1(1)	1 (1)	2 (2)
	Library	2 (5)	0 (2)	-
	Technical institute with laboratories and offices	3 (3)	1 (1)	-
	Residential building with student apartments	2 (6)	0 (2)	-

The measurements took place during the heating season from October 2021 to April 2022. In this period, seventeen heating circuits were evaluated in total. According to Jacob (2010), short-term measurements should exceed at least 14 continuous days to get reliable data. The measurements of the heating circuits were taken in a minimum of 14 days.

In the following sections, exemplary measurement data from different heating circuits are shown and a comparison is made. To eliminate outliers and measurement errors the 0.05 quantile and 0.95 quantile were determined. All measurements include supply and return temperatures and the mass flow of every heating circuit. Outdoor temperatures and sporadic room temperatures were measured as well. Additionally, supply and return temperatures on the primary and on the secondary side of the heat exchangers were evaluated. To identify the heat load of a specific heating circuit out of this measurement data, the following equation (eq. 1) can be applied. The required heat load is a key value to quantify a temperature reduction potential.

Assumption: c_p = *constant*

$$\dot{Q}_{demand} = \dot{m}_{hc} \cdot c_p \cdot (T_{supply} - T_{return}) \qquad \text{(eq. 1)}$$

$\dot{Q}_{demand}$	heat load demand [kW]
$\dot{m}_{hc}$	mass flow [kg h^{-1}]
c_p	specific heat capacity of water [kWh kg^{-1} K^{-1}]
T_{supply}	supply temperature [°C]
T_{return}	return temperature [°C]

2.1. Static heating circuits

In static heating circuits radiators function as heat transfer system for space heating. There exist different types of radiators, e.g. steel column, cast-iron column and panel radiators (Sangi et al., 2015). The heat is distributed by hot water. The water circulates on the secondary side of the heat exchanger at the substation and supplies the heating circuits and by this the rooms. A circulation pump regulates the mass flow. The supply temperature usually is dependent on the outdoor temperature. In many EU countries the design supply temperature is 90 °C whereas the operating supply temperature mostly is under 90 °C (Sarbu, Sebarchievici, 2015). The majority of the heating circuits in the examined buildings are designed with supply and return temperatures of 90/70 °C as well.

In some cases, bypasses are used to regulate the supply temperature in the heating circuits (see simplified heating diagram, Fig. 2). A bypass pipe with a valve connects the return pipe to the supply pipe. Depending on the set point supply temperature the valve opens gradually and cooler water from the return pipe is mixed into the supply to cool it down (Sangi et al., 2015). At Kassel University, bypasses are integrated in the static heating circuits.

As shown in Tab. 1, ten static heating circuits were measured during the heating season 2021/2022. Exemplary measurement data for a static heating circuit in the office and institute building are shown in Fig. 3

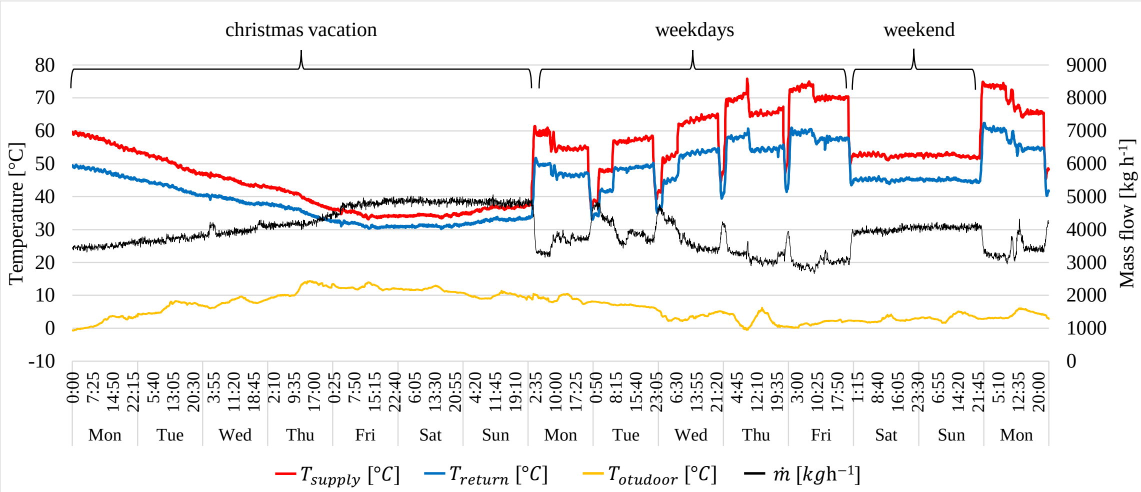

Fig. 3: Measurement data of a static heating circuit in the office and institute building with system temperatures (left axis) and mass flow (right axis), 12/27/2021-01/10/2022

Fig. 3 displays a short section of the measurement from Dec. 27th 2021 to Jan. 10th 2022. A bypass is installed between the supply and return pipe. The supply temperature, measured behind the bypass, is shown in red, the return temperature in blue, the outdoor temperature in yellow (left axis) and the mass flow in black (right axis).

The measurement section shows different periods of use. For regular usage time during the semester, the figure indicates typical weekdays and weekends. A night and weekend temperature reduction is clearly visible. In contrast to the system temperatures, where the supply is lowered by almost 20 K, there is no mass flow reduction during the night and weekend. It actually increases to 5,000 kg h^{-1}. Due to the reduced supply temperature, the thermostatic valves in the rooms open and the mass flow enhances. The room temperature does not drop significantly. The measure values from Monday to Sunday on the left half of Fig. 3 point out the control behavior of the heating circuit during the Christmas vacations. Analogous to the previous observations, the mass flow is not lowered either. This leads to unnecessary heat loss and pump power consumption, which indicates optimization potential in the heating control. The supply temperature decreases continuously to a minimum of 35 °C as the outdoor temperature rises. At the end of vacation the supply temperature increases up to 75 °C, whereas the mass flow decreases. The heat flow is just under 45 kW. Analyses of the whole measurement period resulted in a maximum heat flow of 70 kW appearing at -12 °C outdoor temperature. Despite the closing days and, in some rooms, reduced indoor temperatures of 14 °C, the maximum was not required during the heating phase. An inspection directly after the vacations showed that not all rooms were used and heated up again by turning up the thermostatic valves.

An analysis of the bypass and the bypass valve in the heating circuit over the entire measurement period shows that the actual supply temperature is lowered by the bypass function by around 20 K on average. The supply temperature on the secondary side of the substation has its maximum at 90 °C. The supply temperature measured behind the bypass in the static heating circuit in average is 70 °C. In heating up phases, the supply temperature increases up to 73 °C and the mass flow is 6,500 kg h^{-1}. A heating-up trial, described in chapter 3.1, demonstrated that the maximum mass flow for this heating circuit is 8,000 kg h^{-1}. Compared to the values shown in Fig. 3 this indicates an existing reduction potential even greater than 15 K. Measurements of other static heating circuits revealed the same heating control errors, bypass functions and similar temperature levels.

2.2. Dynamic heating circuits

Dynamic heating circuits heat the supply air of ventilation systems as shown exemplary in Fig. 4. Heat recovery is integrated in the ventilation systems of the examined buildings at the campus. The heating circuit distributes hot water to a heat exchanger, the so-called heater that is connected to the incoming air duct. This heats the supply air temperature to a predetermined set point. The heater does not operate if the outdoor temperature is sufficiently high or if the air temperature provided by the existing heat recovery system is sufficient. In this case, the heating circuit merely circulates without supplying heat to the ventilation system. Generally, the dynamic heating circuit runs as a circulation line like drinking water systems, which leads to circulation losses (Beckmann, 2020).

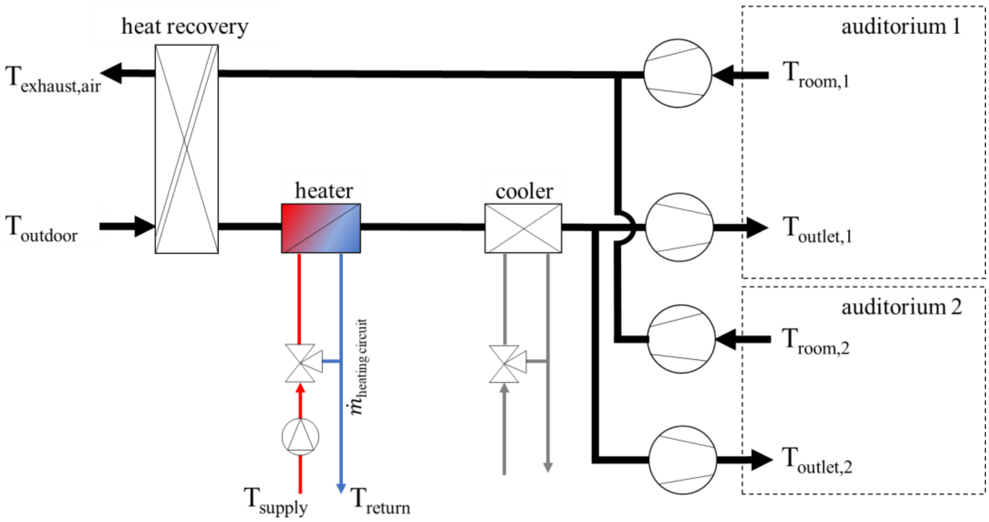

Fig. 4: Simplified diagram of an air ventilation system in a lecture hall at Kassel University

Mass flow, supply and return temperature were measured for four dynamic heating circuits. The heating circuits are connected to air ventilation systems. All of them are equipped with heat recovery as described before. Measurement data indicate that the heating circuits run on high temperature levels, similar to the static heating circuits.

In the lecture hall measures were taken from Feb. 1^{st} to Feb. 16^{th} 2022. Fig. 5 exemplary shows the measured values from Feb. 2^{nd} to 8^{th}. The supply temperature is plotted in red, the return temperature in blue, the outdoor temperature in yellow (left axis) and the mass flow in black (right axis). The heating circuit supplies two auditoriums of approximately the same size. The grey line shows the room temperature for one auditorium. Regarding the room temperature of both rooms, the average is 20.2 °C and 20.5 °C. During the night or at the weekend, the room temperatures do not fall below 18.6 °C respectively 17.2 °C.

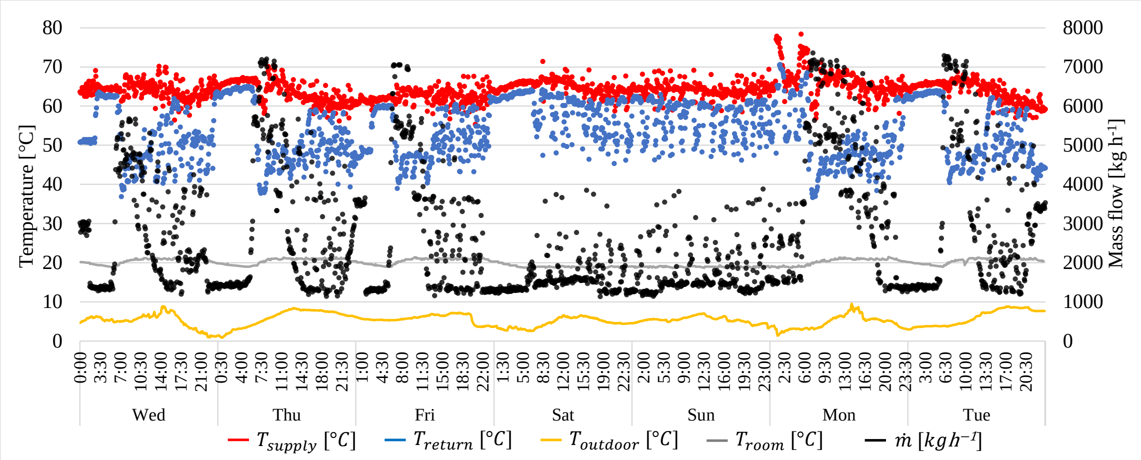

Fig. 5: Measurement data of a dynamic heating circuit in the lecture hall with system temperatures (left axis) and mass flow (right axis), 02/02/2022 – 02/08/2022

Fig. 5 pictures different relations and results of the dynamic heating circuit described above. The mass flow increases when the room temperature falls below 19 °C (set point). In this case, heat is transferred to the ventilation system and the return temperature drops at 40 °C. When there is no heat transfer, the return temperature is similar to the supply temperature, which ranges from 60 °C to 70 °C. The heating circuit runs like a circulation line. This is a common regulation for dynamic heating circuits (Oltmanns, 2021).

Further measurements, not shown in Fig. 5, were analyzed. They point out that the maximum outlet air temperature of the ventilation system, measured behind the heater (see Fig. 4), is nearly 47 °C at T_A^*. It is assumed that this temperature is required to ensure a room temperature of 19 °C. By increasing the mass flow, the supply temperature for the dynamic heating circuit could be reduced. A more detailed analysis is needed at this point.

2.3. Floor heating

In Panel heating systems, large heating surfaces take over the heat exchange. They use the (under-)floor, wall or ceiling as heat transfer systems. Due to the large surfaces panel heating systems can operate at lower temperatures. Floor heating for example runs on a low supply temperature level between 40 °C and 60 °C (Wu et al., 2015). Ceiling radiation panels in high rooms operate at higher temperatures. (Hainbach, 2020). This section takes a closer look at the floor heating system.

Fig. 6 shows exemplary results for a floor heating circuit in a cafeteria from Jan. 5^{th} to 10^{th} 2022. The supply temperature is plotted in red, the return temperature in blue (left axis) and the mass flow in black (right axis). Additionally, the room temperature and the outdoor temperature are pictured in grey and yellow.

The mass flow is almost constant at 1,500 kg h^{-1}. The difference between the supply (on average 38 °C) and return (on average 31.5 °C) temperature is almost constant at 6.5 K. The room temperature averages 21.5 °C and does not fall below 20 °C. There is no reduction in temperatures or mass flow outside cafeteria operating hours. Since floor heating is an inertial system it is not necessary to reduce temperatures for short operating periods (Pech, Klaus, 2015). Furthermore, this system covers the base load depending on the outdoor temperature.

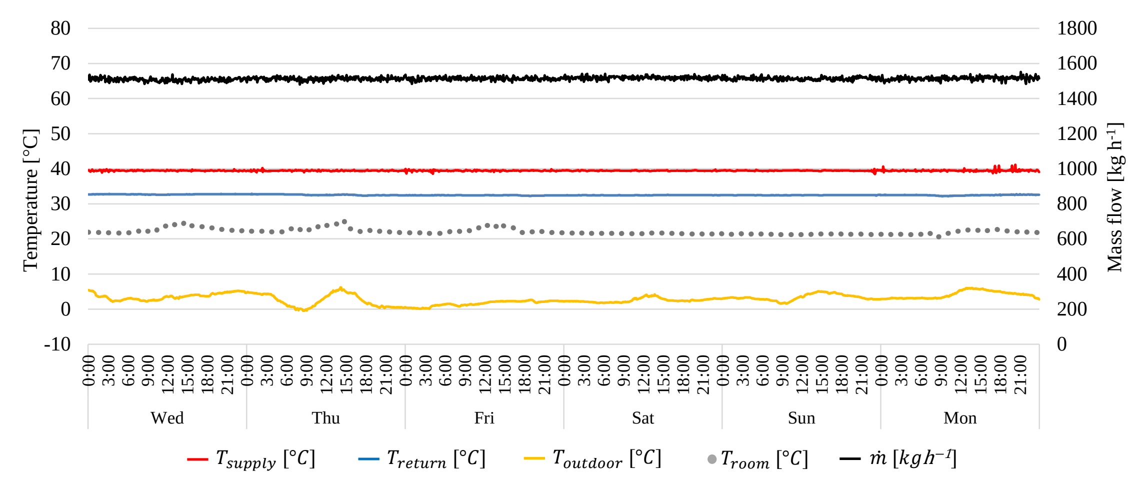

Fig. 6: Measurement data of a floor heating system in the cafeteria of the office and institute building with system temperatures (left axis) and mass flow (right axis), 05/01/2022 – 01/10/2022

Further measurements from February 2022 examined ceiling radiation panels in a lecture hall. Some differences compared to the floor heating system investigated above became apparent. One important point is the higher supply temperature (varies between 50 and 70 °C). In addition, the mass flow fluctuates in a high range. Whereas the return temperature was nearly constant. Thus, that the heating circuit is controlled by the return temperature. At this point, the examination of the ceiling panels is not discussed in detail.

3. Further Approaches

Additionally to measurements addressed in 2. Heating Circuits a heating-up trial and an experimentally reduction-trial of supply temperatures in several buildings and heating circuits were implemented to analyze the impact on the heating system and the room temperatures.

After identifying a critical heating circuit, the critical room(s) regarding possible reduced supply temperatures have to be analyzed. The desired room temperature is considered the criterion and threshold for critical rooms. In Germany, technical workplace regulations preset among other aspects a minimum room temperature depending on the work activity (ASR A3.5). The desired indoor temperature for typical workspaces like offices is 20 °C. This value is defined as set point for the identification of critical rooms.

The reachable room temperature depends on various factors. These include for example the thermal transmission coefficient (U-value) and the thermal mass storage, the geometry, the ratio between external wall area and spatial volume, the placement in the building, the usage, internal and external heat gains (irradiation) and the heat transfer system itself (Bredemeyer et al., 2022). Before installing measurement instruments, those aspects were checked by an on-site inspection. Using a floor plan that marks rooms connected to a specific heating circuit and a prediction which rooms are critical to a reduction of the supply temperature was made after the inspection.

Prediction:

- Rooms on the top floor that are at the end of the heating circuit.
- Rooms that are located in the northern corner of the building.
- Rooms with obvious deficiencies in respect of the heating transfer system.
- Rooms with a large ratio between the external wall surface and the heated volume.

3.1. Heating-up trial

In conjunction with the as critical predicted rooms, measurement instruments were installed and a heating-up trial was implemented in the office and institute building (Tab. 1). The considered static heating circuit supplies 55 rooms, including offices, seminar and conference rooms. The indoor temperature was measured in 20 rooms in which column radiators with thermostatic valves are installed. Furthermore, the supply and return temperatures of radiators were measured in the rooms predicted as critical. In arrangement with the facility management, the thermostatic valves were adjusted to the maximum on Friday, 17th of December 2021. On Monday, 20th of December, the thermostatic valves were adjusted to the baseline again.

As already described before in 2.1. Static heating circuits, the supply temperatures in static heating circuits are usually reduced at weekends. In addition to the reduced temperature (around 40 °C), the thermostatic valves are turned up to the maximum. As illustrated in Fig. 7 the mass flow rate (black) increases probably to its maximum of 8,400 kg h^{-1}. Compared to other measured values, this maximum does not occur during the typical time of use. This mass flow increase leads to a return temperature of around 35 °C (blue). In addition, the supply temperature is shown in red and the outdoor temperature in yellow. In the right third of Fig. 7, the outdoor temperature drops to a range between -10 and 0 °C. Due to the heating circuit control, the supply temperature level increases by about 20 Kelvin to a maximum of 82 °C.

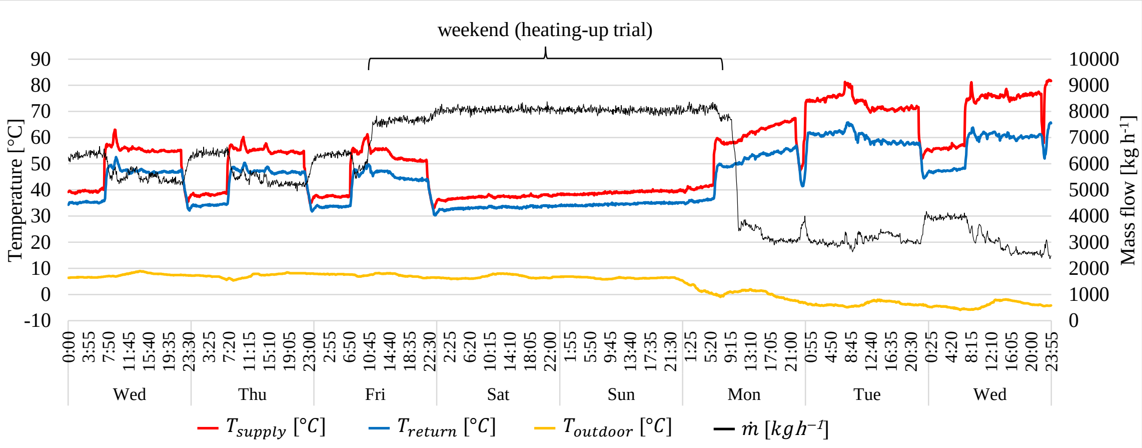

Fig. 7: Measurement data of the heating-up trial in the office and institute building, 12/15./2021 – 12/22/2021

The measured room temperatures during the heating-up trial are shown in Fig. 8. The outdoor temperature drops at a minimum of -1.0 °C on Monday. The average is 5.8 °C. Most of the rooms reach a maximum temperature of around 22 °C. Three outliers reach a maximum of 24 °C to 26 °C (IDs 1103, 1219, 3217). Two offices and one seminar room (IDs 1217, 3104 and 3105) stand out because the temperature does not hit the set point of 20 °C.

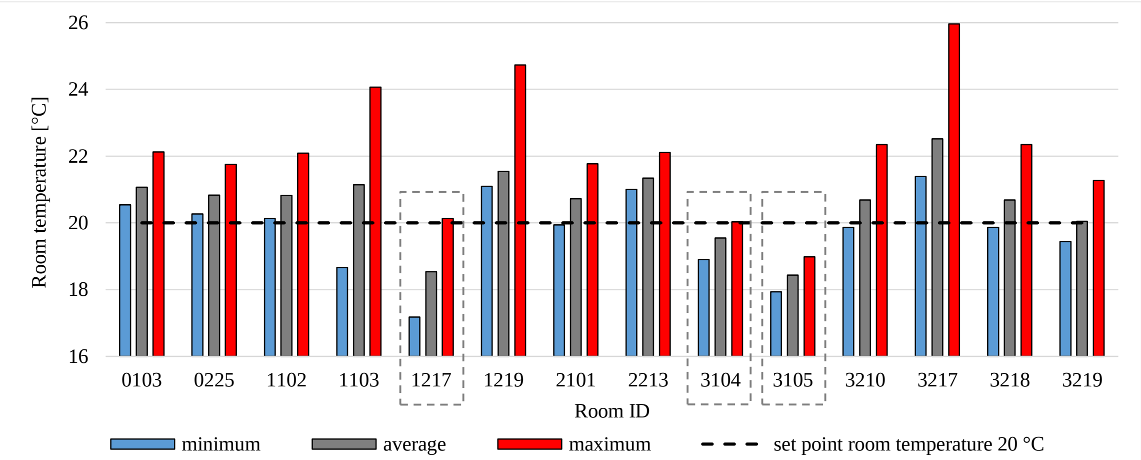

Fig. 8: Measured room temperatures during heating-up trial

In consideration to the predictions, the two offices are located at the end of the heating circuit on the highest floor. The seminar room is located in the corner on the northern side of the building. Besides the location, the seminar room is twice the size of the offices and has two radiators. One radiator is incorrectly connected to the hydraulic system. This needs to be improved. Alternatively, radiators with larger dimensions can replace the existing radiators. This measure leads to a higher radiator capacity and, as a result, a higher room temperature.

The fact that room temperatures of 26 °C are reached in conveniently located rooms indicates the oversizing of radiators. Hasan et al. (2008) state that this is a common practice. For example, the size of radiators often is selected aligning the width of the window "in order to overcome cold draught problems" (Hasan et al., 2008). The oversized radiators are an advantage in regard to possible supply temperature reduction because they "may not necessarily need to be enlarged when operating with a low temperature system" (Hasan et al., 2008).

To examine if the radiator is sufficiently dimensioned with regard to a supply temperature reduction, the general radiator equation (eq. 2) can be used. The installed radiator capacity $\dot{Q}_{90/70}$ for the design otudoor temperature can be detemined by the radiator type and standard boundary conditions (DIN EN 442-2). In this case, the logarithmic mean temperature difference (LMTD, eq. 4) has to be calculated with the design system temperatures. For the office and institute building the design supply and return temperatures are 90/70 °C. The heat load $\dot{Q}_{demand}$ that is acutally required can be analyzed by measurement data. If there is no valid data, the heat load can be estimated using the "Method for calculation of the design heat load - Part 1: Space heating load" described in DIN EN 12831-1. Eq. 3 delivers the required LMTD. With this information, possible temperature pairs (supply and return temperature) can be formed (Jagnow et al., 2003). This approach is currently being tested with further measurement data and will be implemented as an evaluation tool (4.2 Further Works).

$$\frac{\dot{Q}_{demand}}{\dot{Q}_{90/70}} = \left(\frac{\Delta T_{ln,demand}}{\Delta T_{ln,90/70}}\right)^n \qquad \text{(eq. 2)}$$

$$\Delta T_{ln,demand} = \Delta T_{ln,90/70} \left(\frac{\dot{Q}_{demand}}{\dot{Q}_{90/70}}\right)^{\frac{1}{n}} \qquad \text{(eq. 3)}$$

$$\Delta T_{ln} = \frac{T_{supply} - T_{return}}{\ln\left(\frac{T_{supply} - T_{room}}{T_{return} - T_{room}}\right)} \qquad \text{(eq. 4)}$$

$\dot{Q}_{demand}$	heat load demand [kW]
$\dot{Q}_{90/70}$	installed radiator capacity at 90/70 °C [kW]
ΔT_{ln}	logarithmic mean temperature difference [K]
n	radiator exponent [-]

Moreover, a hydraulic balancing is an option to improve the heating circuit (Cho et al., 2020). For example, by reducing the maximum mass flow in rooms with the significantly higher maximum room temperature they would no longer be such outliers. In addition, the reduced mass flow in these rooms could then help to supply the undersupplied rooms.

The heating-up trial additionally indicates the maximum mass flow of the examined static heating circuit. Fig. 7 shows a maximum of 8,000 kg h^{-1}. With the known maximum mass flow and the required heat load, the return temperature can be determined at different supply temperatures (Benakopoulos, 2022).

3.2. supply temperatures reduction-trial

The reduction of supply temperatures in several heating circuits pursued the aim to investigate the development of room temperatures in the buildings. Furthermore, the complaint management was monitored. In preparation, the users were not informed about the trial to avoid foredooming complaints about the temperatures and comfort.

The supply temperatures for the static heating circuits in the library and in the institute building with laboratories were decreased by changing the supply temperature control curve with parallel shift. The university's technical operating department reduced the supply temperature in two 5 K steps. In one heating circuit from 90 °C to 80 °C and in another one from 80 °C to 70 °C for the T_A^* of -12 °C.

The arrow in Fig. 9 marks the date of the 10 K reduction for a heating circuit in the library. In this case, the heating threshold outdoor temperature of 16 °C is already reached and the supply temperature is on a low level (40 °C). In the next days the outdoor temperature decreases constantly to 0 °C. The supply temperature increases to a maximum of around 60 °C and a temperature difference of around 10 K. The considered set point room temperature of 20 °C was reached during the entire test phase. Moreover, there were no complaints from the users regarding the indoor temperatures or comfort. Despite the short period of time and the partly rather high outside temperatures, the trial was successful. The comparison of the four heating circuits involved in the test shows no significant differences in terms of the reduced supply temperature levels.

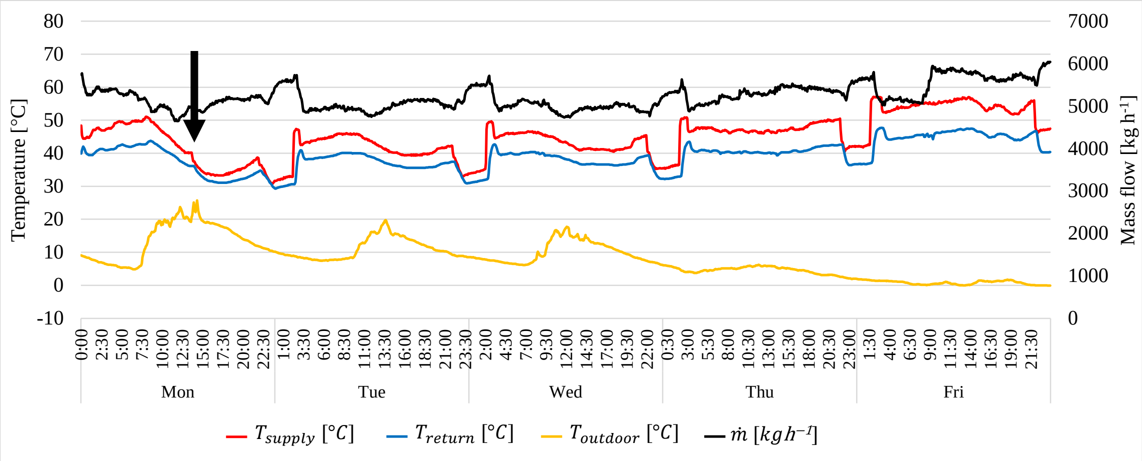

Fig. 9: Supply temperature reduction of 10 K in a static heating circuit in the library

Based on the experiences further trials with reduced supply temperatures are planned for the upcoming heating season (2022/2023). The reduction should be carried out at significantly lower outdoor temperatures and should be increased up to 15 K to 20 K in order to achieve more significant results.

4. Conclusion and Outlook

The research of the Department of Building Services at Kassel University within the project "CampusKassel 2030" is still in progress. The approaches and measurements described above show the further research potential of this project. In this chapter, the optimization potential identified for the different heating circuits and the related heating technology, such as heat exchangers or heating circuit pumps, so far will be highlighted. Furthermore, a transferable methodology for the identification of temperature reduction and optimization potentials will be developed. The current status of this methodology and the further procedure are described below as well.

4.1. Identified optimization potential

The measurements of different heating circuits showed that there exist several optimization factors regarding the temperature reduction potential. Those factors mainly relate to the heating control and components. The on-site inspections showed that water circuit pumps and heat exchangers are partly up to 40 years old with a high energy demand. The connection between heating pipes and renewed pumps are not insulated. Especially the insulation of flanges often is a weak point. As a result, distribution losses of the heating systems increase unnecessarily. Those vulnerabilities easily can be avoided. In many heating circuits bypasses are integrated that lower the supply temperature of the water on the secondary side of the heat exchanger (substation) before entering the heating circuit. This indicates the potential for reduced system temperatures. Furthermore, efficient plate heat exchangers have better transformation values compared to the existing heat exchangers and can therefore be decisive for a network temperature reduction. At Kassel University, the building service department is gradually renewing the heating circuit distribution stations. The presented results support this renewing process.

In the static heating circuit described above (chapter 2.1.) it is highly recommended to implement a night and weekend shut-off to the water circulation pump. Attention must be paid to higher heating loads during heating phases in the morning or after weekends. It should be verified that the energy savings are commensurate with the additional expense. This is transferable to other static and partly dynamic heating circuits. Efficient circuit pumps with an efficient control should be integrated in a first step. This step leads to reduced power consumption for the pumps and through a suitable regulation to fewer distribution losses outside operating hours. By increasing the mass flow, the supply temperature can be decreased. For example, the supply temperature of examined office and institute building can be reduced by at least 15 K in relation to the design outdoor temperature as explained in chapter 2.1. This reduction is currently being implemented as part of the renewal of the substation.

Regarding the dynamic heating circuits (chapter 2.2), a large reduction in supply temperatures is possible by setting user-oriented target values. In one case, the examination revealed that the supplied rooms need to be cooled instead of being heated. Still, the dynamic heating circuit runs on high supply temperatures with no efficient circuit pump regulation. An outdoor temperature range must be defined above which pump shutdown can occur.

The evaluation of the measured values shows that the floor heating system has the lowest system temperatures, as expected. There exist no reduction potential for the considered heating circuit in chapter 2.3. Panel heating circuits like ceiling radiation panels operate at a higher temperature level. In a further step it has to be worked out how large the reduction potentials are in this systems.

Examination on the room level lead to the identification of critical rooms in a specific static heating circuit (chapter 3.1) regarding the temperature reduction potential. In a next step the heat load of those rooms and the dimension of the radiators are to be calculated. With this information, radiators with correct dimension can replace the undersized radiators in the critical rooms.

It is difficult to give an overall advice for a quantification of temperature reduction potential. The non-residential buildings at Kassel University are very different in addition to their use, year of construction, types of heating circuits and especially their heat demand. An increased mass flow enables reduced supply temperatures with the required heat flow (see eq. 1). At the same time an enhanced mass flow results in a higher electricity demand. An optimum is to be determined. Thereby, it is important to integrate a gradual temperature reduction as described in 3.2. Reduction of supply temperatures. Low outdoor temperatures should be a condition for safe and satisfactory implementation.

4.2. Further Works

To make use of the results described above a universal methodology to identify temperature reduction and optimization potential for the investigated non-residential buildings based on measurement data, a "minimum temperature analysis" will be developed. The aim of this analysis method is to make a qualified statement about the minimum supply temperature for space heating in non-residential buildings based on district heating with little data. The method is implemented as an evaluation tool in Microsoft Excel. It displays a substation, heating circuits including bypasses and water pumps and rooms of a building. The heat load of the building and the heating circuits will be modeled with measurement data. Based on these information, a parametric study with various supply temperatures, mass flows and heating control can be made. This methodology is to be verified by measurements in the next heating period and by further experimentally supply temperature reductions. In general, the methodology will be developed with the aim of evaluating different campus buildings and making the approach transferable to other areas and universities.

In addition, cooperation with the building service department should be maintain. The identification of critical buildings and critical heating circuits can lead to a changed sequence for the renewal of the heating substations. Furthermore, hydraulic balancing of the heating circuits should be implemented. Subsequently, identified weak points on the room level can be eliminated by activities such as window replacement or heating surface extension.

In the future, the minimum temperature analysis could be used to map large building pools such as the University of Kassel to determine system temperature reduction potentials with little measurement effort. After the implementation and the commissioning of relevant measures, reduced supply temperatures of specific heating circuits can be optimized and adjusted step by step.

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Nomenclature:

ΔT_{ln}	logarithmic mean temperature difference [K]	T_{A^*}	design outdoor (ambient) temperature [°C]
c_p	specific heat capacity of water [kWh kg^{-1} K^{-1}]	$T_{exhaust,air}$	air temperature released to the outside [°C]
hc	heating circuit [-]	T_{outlet}	air temperature conducted into a room [°C]
$\dot{m}$	mass flow [kg h^{-1}]	T_{return}	return temperature [°C]
n	radiator exponent [-]	T_{room}	indoor temperature [°C]
$\dot{Q}$	heat load [kW]	T_{supply}	supply temperature [°C]