TRANSFORMATION OF A UNIVERSITY CAMPUS: COMPARISON OF RANKING METHODS FOR TEMPERATURE REDUCTION FROM NETWORK AND BUILDING PERSPECTIVE

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Abstract

This paper aims to find an approach to reduce temperature levels in a district heating subgrid and the supplied buildings at the University Campus in Kassel. The Campus consists mostly of non-residential buildings with high building supply temperatures. The district heating network was built in the 1980s. Consequently, there is a need for structured renovation to achieve higher energy efficiency, better integration of renewable energy sources and therefore lower greenhouse gas emissions. Methodically, two different methods for identifying temperature reduction potentials are used to determine which buildings should be focused on when transforming to low temperature supply. The two ranking methods, the Kappa method and the excess flow method, are introduced and discussed. Since the excess flow method is more established and has already proven its uses, it has been used to validate the new Kappa method. It was shown that the ranking from the Kappa method is comparable with the excess flow ranking, while still offering a distinct viewpoint from a different technical field. The weaknesses discovered in the Kappa method will be further developed and adapted in the future using various implementable factors. Furthermore, an extrapolation approach will be used to make statements about the approximate design state of the buildings.

Keywords: district heating, temperature reduction, University Campus, non-residential building, excess flow, faulty substations, Kappa method, heating circuit, technical building equipment

Transition to 4GDH

Nomenclature:

$\dot{Q}_{Pri}$	heat demand per hour primary side [kW/h]		
$\dot{Q}_{Geb,m}$	heat demand per hour calculated with heat loss H_{ges} [kW/h]		
$\dot{Q}_{GLT,h}$	heat demand per hour calculated with heat loss $H_{eq,h}$ [kW/h]		
$\dot{Q}_{WD}$	weather-independent demand [kW/h]]		
$\dot{Q}_{demand}$	heat demand per year [MWh/a]	$H_{eq,h}$	dynamic heat loss of the building [kW/K]
κ	Kappa factor	H_{ges}	stationary heat loss of the building [kW/K]
$T_{s,h}$	hourly supply temperature [°C]	$\dot{m}$	mass flow [kg/h]
$T_{r,h}$	hourly return temperature [°C]	$\dot{m}_{max}$	maximum mass flow [kg/h]
$T_{interior}$	interior space temperature steady 20 °C	$\dot{V}_a$	annual volume flow [m³/a]
T_a	related ambient temperature [°C]	$\dot{V}_{excess}$	excess flow [m³/a]
$T_{r,a}$	annual return temperature [°C]	$\dot{V}_{target}$	target volume flow [m³/a]
$T_{r,target}$	annual target return temperature [°C]	c_p	specific isobaric heat capacity [kWh/(kg·K)]
$T_{s,a}$	supply temperature annual [°C]	ρ	density [kg/m³]

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1. Introduction

Network temperature reduction is a prerequisite to realize smart energy systems and smart thermal grids as well as 4th Generation district heating (4GDH) systems . The goal of all these concepts is a 100 % renewable energy system without greenhouse gas emissions. Fault detection and rectification plays an important role to achieve temperature reduction, especially in existing networks. Therefore measurement data is used to achieve this (Månsson et al. 2018; Xue et al. 2017; Zinko et al. 2005). Faults and other limitations to temperature reduction can be found both on the primary (district heating network) and the secondary side (building level) of the substations. Typical faults are described e. g. in (Månsson et al. 2019; Bergstraesser et al. 2021).

One field where the application of new methods to achieve temperature reduction can be tested are the universities where the research is conducted, therefore multiple projects to reduce greenhouse gas emissions are and have been realized there. For example, the Bremen University of Applied Sciences, Düsseldorf University of Applied Sciences or the University of Bremen have developed climate protection concepts (Wilk et al. 2020). Many German universities are currently working on projects to improve energy efficiency, especially in the field of district heating. The TU Dresden has taken a holistic approach to energy efficiency as part of the Leuphana University of Lüneburg Climate Neutral Campus project (Opel et al. 2018). For this purpose, the fields of energy, campus development and transport were analyzed with an integral approach. Also at the TU Dresden, research has been conducted on the decentralized feed-in of solar energy and its contribution to the decarbonization and flexibilization of modern district heating networks (Rosemann et al. 2017). The Institute for Energy and Environmental Research Heidelberg (ifeu) shows transformation strategies from fossil central district heating supply to grids with higher shares of renewable energies (Paar et al. 2013).

The research project "EnEff:Stadt/Campus: Campus Kassel 2030 - Concepts and Measures for the Accelerated Implementation of the Energy Transition in Higher Education" (CK2030) integrates into these research topics. CK 2030 deals with the climate neutrality of the University campus in Kassel. The main goal of the project is to reduce greenhouse gases emitted by the building’s heating supply. The university's own local heating network supplies 20 mostly non-residential buildings with local heat and is fed from the municipal district heating network. The network of the University of Kassel was built in the 1980s and requires renovation due to its age. Since the entire network is to be rebuilt, this offers the opportunity for coordinated planning with the aim of achieving the energy efficiency targets for reducing greenhouse gases. A key goal of the project is to reduce the temperatures at which the buildings are supplied, and thus reduce the network temperature. The supply and return temperatures are currently very high (130 °C / 75 °C). With lower temperatures, renewable energies could be better fed into the heating network, and the efficiency of the grid and the buildings could be increased, because lower temperature losses occur. The research project attempts to gain a complete overview of the existing situation on the campus and to depict the current state as well as to identify potential for reduction. Here, both the viewpoints from the network perspective as well as the viewpoint from the building level, up to the heating circuit or room level, are examined. This paper deals with two methods that aim to analyze larger pools of buildings and identify buildings that are critical for lowering the grid temperatures. The newly developed Kappa method attempts to identify the dimensioning condition of mass flow and temperature levels using measurement and consumption data to produce a building ranking. The Excess flow analysis sorts buildings based on their excess volumetric flow and defines a high return temperature as critical. After the presentation of both methods, they are to be compared with each other trying to evaluate Kappa as a newly introduced method, to determine differences and to identify temperature reduction potentials.

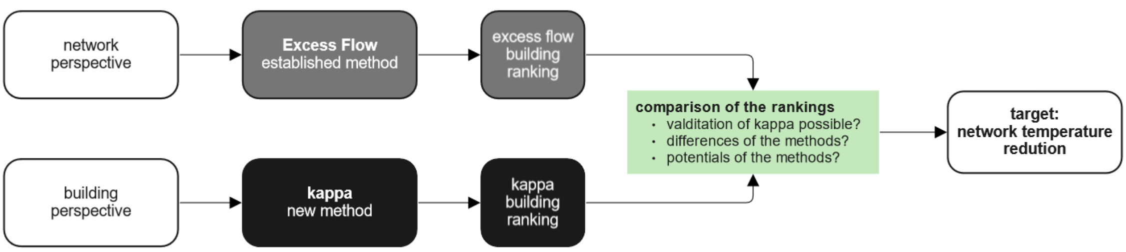

Fig. 1: Systematic structure of the overall approach

2. Kappa method

The Kappa method is currently still under development. The aim of the method is to examine a large pool of buildings for critical ones using as little measurement data as possible. For the method, only measurement data from the primary side of the buildings is used, i.e. only data from the substations heat flow meters. Heat demand, temperature, and mass flow data in hourly aggregation are evaluated at outside temperatures warmer than the design temperature for Kassel of -12 °C (acc. to DIN-TS 12831-1). Based on this data, the buildings that would be critical for a reduction of the network temperature can be identified. Once identified, the critical buildings are to be investigated in a prioritized manner at the heating circuit and room level in order to determine specific reduction potentials. These more in-depth detailed investigations are also being developed as part of the CK 2030 research project and described in the EuroSun 2022 conference paper 'Identification of Temperature Reduction Potentials in Heating Circuits based on Measurements' (Fox, Schüler, Knissel).

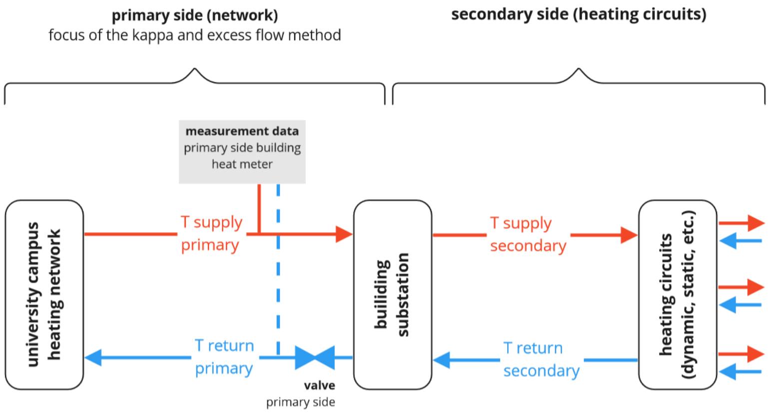

Fig. 2: Schematic diagram of a substation

Kappa combines temperature studies and mass flow studies relative to outside temperature. With the help of the Kappa factors a building ranking is to be provided, which serves for the decision of further investigations of the buildings on the heating circuit level or the room level. Kappa always aims at the design conditions of the buildings, i.e., for Kassel the required heating capacity of the buildings at -12 °C outside temperature. Since it cannot be assumed that measurements during the design state are possible, another goal of the Kappa method is to extrapolate to the design state with measurements outside the dimensioning conditions. The retrieved data from the operating technology database are in the core heating months, i.e., November through March.

Kappa factors can be used to make statements about the spread and mass flow characteristics of buildings. Buildings with a low Kappa factor have a low primary side spread and high mass flow at dimensioning conditions and buildings with a high Kappa factor have a large spread with low mass flow. To calculate Kappa with the help of capacities and to analyze further extrapolation methods, the heating loads of the buildings were calculated with different methods as a basis, the consumption analysis according to DIN-TS-12831 and the EAV analyses (energy analyses from consumption) (Wolff et al. 2019). The EAV method evaluates the efficiency of buildings and energy supply as well as user behavior based on consumption measured at monthly or weekly intervals. The calculated performances of the DIN-TS 12831 analysis were used for the further investigations.

2.1 Calculation of the Kappa factor

In the following, the calculation of the Kappa factor and its derivation is explained. The initial equation of the Kappa approach equates two heat flows (e.q. 1). $\dot{Q}_{Pri}$ describes a heat demand per hour on the primary side of the building and is calculated using the hourly values of the mass flow and the supply and return temperatures. $\dot{Q}_{Geb\,,m}$ calculates the heat demand via the heat loss of the building and the temperature difference between the outside and interior temperature:

$$\dot{Q}_{Pri} = \dot{Q}_{Geb,m} \text{ with } \dot{Q}_{Pri} = \dot{m}\, c_p \left(T_{s,h} - T_{r,h}\right) \text{ and } \dot{Q}_{Geb\,,m} = H_{ges}(T_{interior} - T_a) \qquad \text{(eq. 1)}$$

H_{ges} describes the heat loss of a building and is usually based on the temperature difference of the outside temperature (often in 1 Kelvin steps). Since the determination of H_{ges} from monthly values is a steady state, an additional hourly dynamic heat loss coefficient $H_{eq,\,h}$ is formed to check the approach. H_{ges} corresponds to the slope of the parallel-shifted straight line from the approximate determination of the building heating load according to DIN/TS 12831-1. The analysis according to DIN 12831-1 was carried out parallel to the Kappa method using consumption data on a monthly basis of the buildings over the last three to four years. $H_{eq,\,h}$ as a dynamic coefficient is formed from the measured data in hourly aggregation (e.q.2).

$$H_{eq,h} = \frac{\dot{m}\, cp\,(T_{s,h} - T_{r,h})}{(T_{interior} - T_a)} \qquad \text{(eq. 2)}$$

For the approach, the capacity of the different calculable heat flows are compared, so that an evaluation of the differences between dynamic and steady-state consideration is possible (eq. 3). The following heat flows are used. $T_{interior}$ is assumed as static interior temperature with 20°C acc. to (ASR A3.5 2010).

$$\dot{Q}_{GLT\,,\,h} = H_{eq,\,h}(T_{interior} - T_a) \text{ and } \dot{Q}_{Geb,\,m} = H_{ges}(T_{interior} - T_a) \qquad \text{(eq. 3)}$$

If the building under consideration is a substation that simultaneously represents weather-independent demands, e.g. hot water, both the heat flow and the Kappa factor must be added by the weather independent demands (eq. 4). $\dot{Q}_{Geb,m}$ is then calculated as follows:

$$\dot{Q}_{Geb,m} = \dot{Q}_{WD} + H_{ges}(T_{interior} - T_a) \qquad \text{(eq. 4)}$$

During the investigation it was found that the steady-state and dynamic heat flow are comparable. Equating the heat flows is possible because the dynamically calculated capacity $\dot{Q}_{GLT\,,\,h}$ with $H_{eq,h}$ is identical to the calculated capacity from $\dot{Q}_{Pri}$. By the equation of the two heat fluxes the following transformation for dimensionless Kappa can be derived (eq. 5).

$$\dot{Q}_{Pri} = \dot{Q}_{GLT\,,\,h} \text{ equals } \dot{m}\, cp\, \left(T_{s,h} - T_{r,h}\right) = H_{eq,h}\, (T_{interior} - T_a)$$

$$\boldsymbol{\kappa} = \frac{(T_{s,h} - T_{r,h})}{(T_{interior} - T_a)} = \frac{H_{eq,h}}{c_p\, \dot{m}} \qquad \text{(eq. 5)}$$

When considering including weather-independent demands, such as water heating, the calculation must be completed with the weather-independent capacity (eq. 6).

$$\kappa = \frac{(T_{s,h} - T_{r,h})}{(T_{interior} - T_a)} = \frac{H_{eq,h}}{cp \cdot \dot{m}} + \frac{Q_{WD}}{\dot{m} \cdot c_p \cdot (T_{interior} - T_a)} \qquad \text{(eq. 6)}$$

The idea of the approach is that Kappa at conditioning temperature can also be determined from the steady-state observation with H_{ges} (eq. 7). For this, however, the maximum mass flow of the system must be known. The derivation of the maximum mass flow approach and the possibility of extrapolation are explained in more detail in section 1.6.

$$\kappa = \frac{H_{ges}}{c_p \cdot \dot{m}_{max}} \qquad \text{(eq. 7)}$$

$\dot{Q}_{Pri}$	heat demand per hour primary side [kW/h]		
$\dot{Q}_{Geb,m}$	heat demand per hour calculated with heat loss H_{ges} [kW/h]		
$\dot{Q}_{GLT,h}$	heat demand per hour calculated with heat loss $H_{eq,h}$ [kW/h]		
$\dot{Q}_{WD}$	weather-independent demand [kW/h]]		
$H_{eq,h}$	dynamic heat loss of the building [kW/K]	H_{ges}	stationary heat loss of the building [kW/K]
$T_{s,h}$	hourly supply temperature [°C]	$\dot{m}$	mass flow [kg/h]
$T_{r,h}$	hourly return temperature [°C]	$\dot{m}_{max}$	maximum mass flow [kg/h]
$T_{interior}$	interior space temperature steady 20 °C	c_p	specific isobaric heat capacity [kWh/(kg·K)]
T_a	related ambient temperature [°C]	κ	Kappa factor

2.2 Estimation of the Kappa factor

Using the Kappa calculation based on the temperature differences (e.q. 5), Kappa factors can be calculated for different outside temperatures and spreads. The Kappa factors are generally valid for those different temperature spreads in relation to the outside temperature and can be estimated as shown in Tab. 1. The generally valid Kappa values (y-axis) can be plotted graphically against the outside temperature (x-axis) (Fig. 3) and give an indication about the behavior of the Kappa factors in relation to the outside temperature.

Estimation of substation dimensioning	$\Delta T_{supply-return}$ at -12 °C T_a	Kappa factor
Large	10 K	0,31
Exactly	40 K	1,25
Small	60 K	1,88

Tab. 1: Estimation of Kappa factors

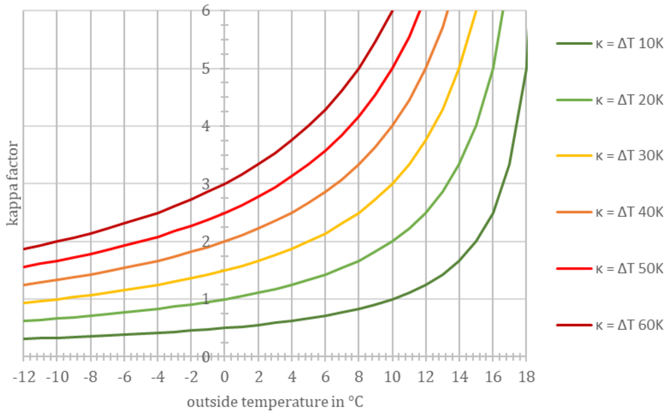

Fig. 3: General Kappa factors for different temperature spreads applied over the outside temperature

2.3 Kappa analysis for an example building

The Kappa factors that can be calculated for each building from the measurement data of the building control system can be entered in the basic diagram for better graphical classification (Fig. 4). The hourly calculated Kappa factors (y-axis) and their characteristics along the base Kappa factors can then be visualized in reference to the outside temperature (x-axis). The relationships between Kappa factor, dimensioning condition, spread, and mass flow are then easier to read in relation to the general Kappa values. Also, the behavior of the building in relation to the outside temperature is clearly readable.

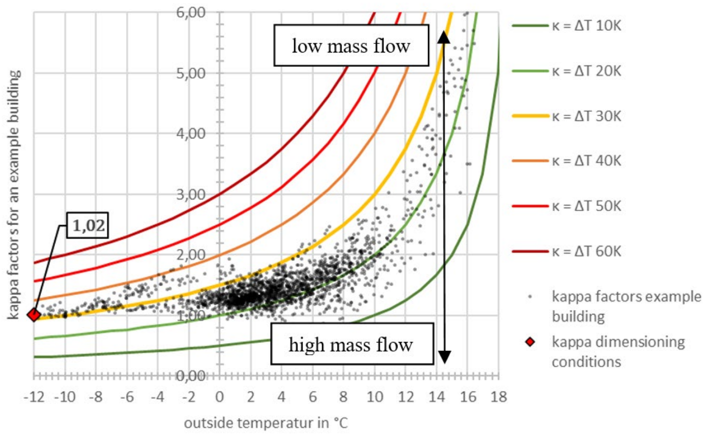

Fig. 4: Kappa factors for an example building with Kappa factor at dimensioning condition -12 °C

2.4 Results campus analysis with Kappa

The building stock of the south campus was analyzed with Kappa. Because measurement data were available that lie within the dimensioning condition – 12 °C (measurement period January 2021 to March 2021, temperatures down to approximately -17 °C), an extrapolation to dimensioning condition wasn`t necessary. The extrapolation approach is explained in more detail in section 1.6. The Kappa factors were compared in a ranking (Fig. 5). Therefore, they were graphically plotted for each building at dimensioning conditions (y-axis left) and the corresponding spreads were placed on the second y-axis for a better graphical overview. These factors are not a specific Kappa value at -12 °C but the average of the Kappa values between -11 °C and -13 °C.

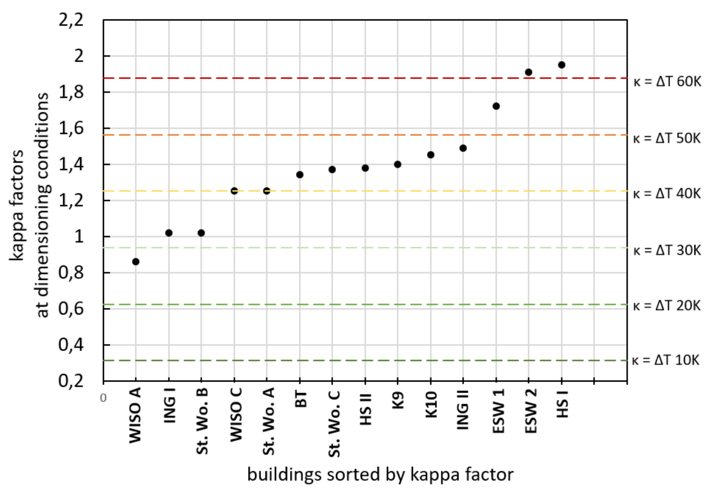

Fig. 5: Building ranking by Kappa factor – less critical with low Kappa factor, more critical with high Kappa factor for the university campus

Depending on other known building factors, such as year of construction, renovation status, etc., the result is unexpected, as new buildings are identified as critical for network temperature reduction. A low temperature spread on the primary side has a beneficial effect on the regulation of the heating circuit level. If the spread is increased on the primary side, this does not necessarily have a direct effect on the secondary side and thus does not result in an adjustment of the temperature spread on the heating circuit level. The oversizing of the substation can be used to generate the required heating output. The limiting factor of the system is then the maximum deliverable mass flow.

For each building, a Kappa diagram similar to Fig. 4 was generated. Upon closer examination of the respective Kappa data sets and examination of the resulting Kappa diagrams for each building, different types of buildings were identified.

2.5 Learnings different building types

It was discovered that the originally assumed unregulated approach (that a maximum mass flow is present in all buildings) does not apply. By comparison of all buildings graphics three building types could be identified:

- Type M: In these buildings, the maximum mass flow is applied on the primary side (Fig. 6)
- Type dT: The temperature level, spread and mass flow of the building is regulated according to the outside temperature and along a predetermined spread (Fig. 7)
- Type flex: Is unclearly regulated. By eliminating operating hours and weekend setbacks, type flex buildings can be assigned to type dT buildings.

Compared to a conventional control of substations, the type M is more unusual and not preferable. Modern substations are usually regulated in the same way as the dT building types.

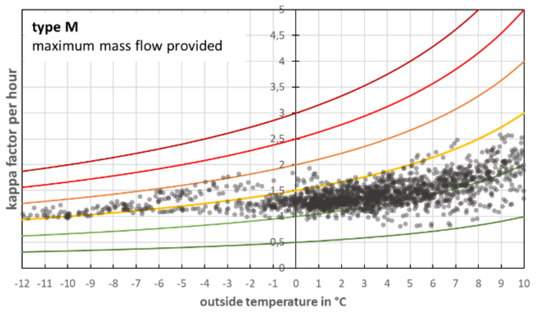

Fig. 6: Kappa analysis type M building

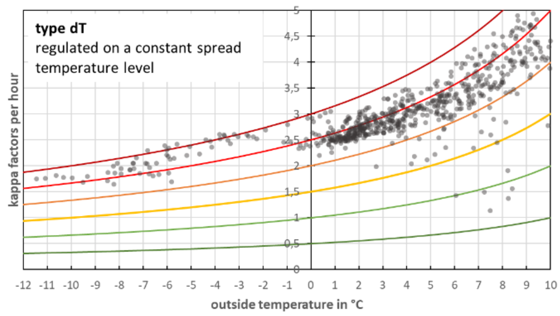

Fig. 7: Kappa analysis type dT building

2.6 Extrapolation approach dimensioning conditions

In order to test the original goal of the Kappa approach, the use of measurement data outside the dimensioning temperature and the extrapolation to dimensioning conditions, the existing measurement data was examined in different time periods. For this purpose, the original data set from January 2021 to March 2022 was divided into three monthly periods of four weeks. To check the plausibility of the individual data records and the possibility of extrapolation, the maximum mass flow calculation (eq. 7) was used for the example building. The data of the maximum mass flow was preselected and only the average of the upper 5% percentile was used. For buildings of type M, the Kappa of the dimensioning condition could be calculated approximately from these maximum mass flow Kappa values of the respective monthly periods. In comparison, the Kappa factors of the individual months are as follows: January $\kappa = 1{,}02$ (green), February $\kappa = 0{,}97$ (purple) and March $\kappa = 0{,}95$ (blue). The average Kappa factor for the example building at dimensioning condition according to Fig. 4 is $\kappa = 1{,}02$. The calculation is approximately accurate by +/- 5 K spread at design level or else deviates by 0.07 among the Kappa factors (Fig. 8). The Kappa factors were plotted against the average outdoor temperature for the measurement period. Thus, for buildings of type M a rough extrapolation to dimensioning conditions via the calculation of the steady-state heat loss coefficient and the maximum mass flow (eq. 7) is possible. For buildings of type dT and flex this does not apply. The reason for this is that the maximum mass flow cannot be derived from the Kappa factors which are controlled by a predetermined spread according to the outside temperature. Thus, it is unknown whether the Kappa factor at design condition corresponds to the maximum mass flow of the system or not. In addition, calculations were carried out for the dT types and produced unplausible results for the Kappa extrapolation.

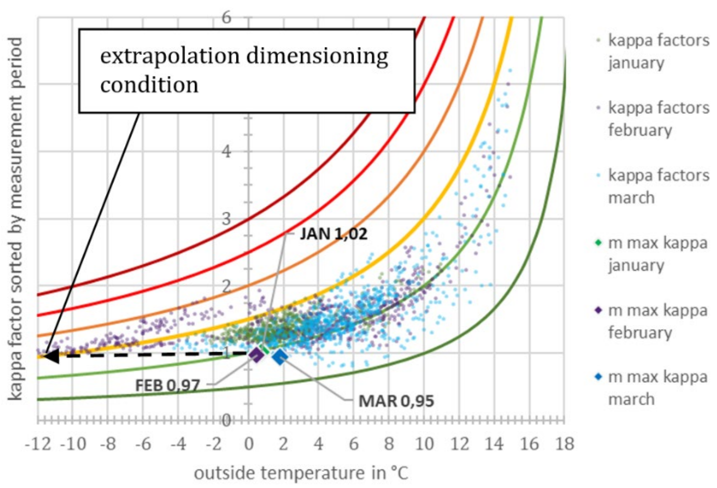

Fig. 8: Extrapolation for a Type M building to dimensioning conditions with Kappa factors and measurements beyond dimensioning condition

2.7 Outlook Kappa

The Kappa method yields a ranking prioritizing the regulation potential of a building. Buildings with a low Kappa factor should be more easily adjustable to a lower network temperatures and buildings with a high Kappa factor could be more critical. The reason for this is the assumption that buildings with a high temperature spread and high mass flow on the primary (network) side are already maxed out during dimensioning conditions and have less regulation potential on the secondary (heat circuit) side. At the moment, Kappa doesn't define a potential of temperature reduction yet and is focusing on the "as build" or better "in use" status of the buildings and heat exchangers. Fig. 5 has shown the Kappa factors for the period from 01.01.2021 to 31.03.21 and their level of temperature spread in dimensioning conditions. The Kappa factor was able to presort critical buildings out of the stock but for further analysis the ranking needs to be adjusted. In further steps Kappa needs to be corrected by other factors. To finalize the ranking aspects like the building's year of construction, the year of installation of the heat exchangers (state of renovation), the temperature spread on the heat circuit level and the kind of heat circuits (static, dynamic, hot water, etc.) could be considered and weighted. A type assignment of the different Kappa building types via the building use is currently not possible. Current evaluations show that the age of a substation could be a hint for a type M or type dT buildings.

Since Kappa can only be extrapolated for type M buildings and the mass flows for the types dT are not known, the different types and Kappa factors cannot be clearly compared. So, the goal of the extrapolation approach (Fig. 8) only works for buildings that have type M in and thus provide comparability. The goal of the upcoming research steps is also to correct the Kappa factors of the type dT buildings. Based on the available valve position data, which is accessible via the building control system, Kappa for dT buildings could be corrected. The maximum mass flow could then be calculated with this valve data and thereby provide comparability among the buildings Kappa factors. If this correction for Kappa is possible, Kappa factors could be determined for large building stocks of type M and dT with little effort. Only the information for H_{ges} from a DIN/TS 12831-1 demand analysis and the maximum mass flow (eq. 7) plus the correction factor for the valves would be needed.

3. Excess flow method

Many substations in existing district heating (DH) grids do not achieve an optimal efficiency which often corresponds to high return temperatures. In order to achieve lower return temperatures, the excess flow method was developed in the IEA DHC Annex VII "Improvement of Operational Temperature Differences in District Heating Systems" (Zinko et al. 2005). It allows to identify those customers that contribute the most to a high return temperature. Higher than required volume flow rates through a substation are the cause of unwanted high return temperatures. That is why, for each substation an excess flow is calculated, that is equal to the difference of the actual volume flow from a target volume flow, see (eq. 8).

$$\dot{V}_{excess} = \dot{V}_a - \dot{V}_{target} = \frac{\dot{Q}_{demand}}{\rho \cdot c_p} \cdot \left(\frac{1}{T_s - T_{r,a}} - \frac{1}{T_s - T_{r,target}}\right)$$

(eq. 8) (Heimo Zinko et al. 2005)

$\dot{Q}_{demand}$	heat demand per year [MWh/a]		
$T_{r,a}$	annual return temperature [°C]	$\dot{V}_a$	annual volume flow [m³/a]
$T_{r,target}$	annual target return temperature [°C]	$\dot{V}_{excess}$	excess flow [m³/a]
$T_{s,a}$	supply temperature annual [°C]	$\dot{V}_{target}$	target volume flow [m³/a]
ρ	density [kg/m³]	c_p	specific isobaric heat capacity [kWh/(kg·K)]

To define the target volume flow, a target temperature difference is needed, it is composed of the yearly mean supply temperature and a yearly mean target return temperature. All temperatures should be weighted by the volume flow to get an accurate measure of the influence on a raised return temperature. The application of the excess flow method and its validation for fault detection is described in more detail in (Bergstraesser et al. 2021).

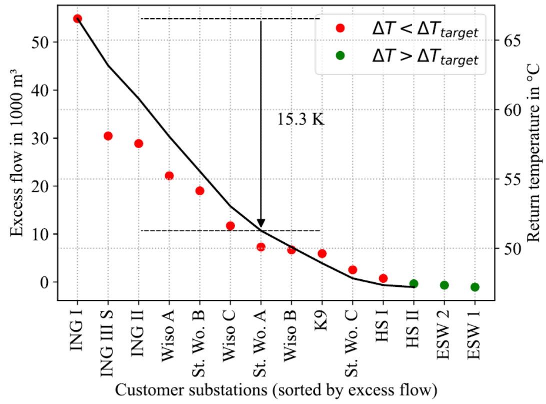

Fig. 9: Excess flow ranking with return temperature reduction

Fig. 9 shows the calculated excess flow for the year 2021 from 22.01.2021 to 26.01.2022 and includes all substations that were accessible. The substations (x-axis) are sorted by excess flow and represented by points colored in accordance with whether or not they reach the target temperature difference. A positive excess flow i.e., a higher than target return temperature is colored red, while a negative excess flow i.e. a lower than target return temperature is colored in green. Additionally, the return temperature reduction is shown when measures in substations are taken depending on the ranking by excess flow. E.g. measures in six substations, that achieve the target temperature difference, will result in a return temperature reduction of about 15 K for the whole network.

4. Comparison of the methods

Since the excess flow method has already been validated for multiple substation types, it can be used to compare the results from the Kappa method. Fundamentally, the methods show two different points of view. The excess flow method shows the view of the local heating network and ranks substations according to return temperature. The Kappa method analyses the buildings in the first step independently of the local heating network and tries to identify the regulation potential of the buildings. The secondary side (heating circuits) of the buildings is thereby not yet observed. Since one method identifies regulation potential and the other looks for errors in the regulation, the building rankings are, as expected, not identical. If the two rankings are plotted against each other, it is noticeable that they are almost opposite. This is shown in Fig. 10, which confirms the differences since a high value of Kappa, or a high excess flow is considered indicative for a critical building in both rankings.

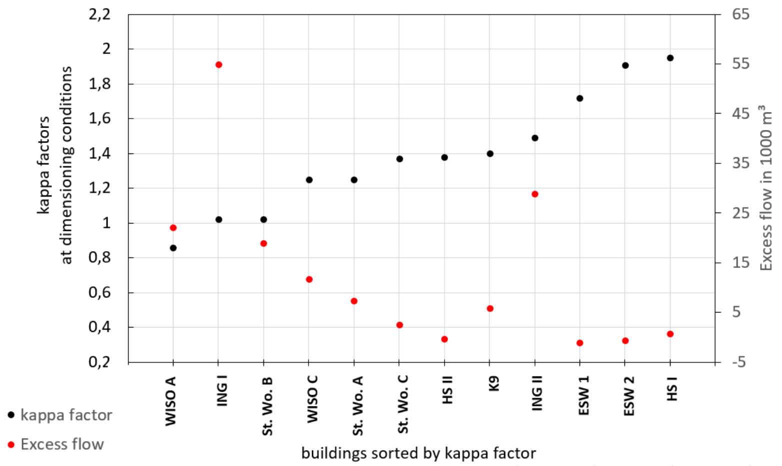

Fig. 10: Kappa ranking sorted by building and displaying the respective excess flow

By generating the reciprocal of Kappa, the readability between the two rankings was further improved (Fig. 11). It can be observed that the rankings are almost identical, with a few exceptions. Differences between the two methods can be attributed to various factors. Kappa only considers measurement data from a winter period and at dimensioning condition of -12 °C. In addition, Kappa is based on an aggregation on an hourly basis. Furthermore, different factors are included in the Kappa factor ranking, such as the measured spread, the mass flow, the heat loss coefficient, and the dimensioning temperature of the interior spaces. Excess flow is calculated on the basis of the target network temperature, the heat demand of the building and the current return temperature. These are annual average values. The excess flow ranking is also weighted by the amount of total heat demand per building/ substation. Fig. 9 shows this deviation very clearly, as the buildings ING I, K9 and ING II are buildings with a high heating requirement, building volume and floor space. These buildings differ greatly in their ranking between the excess flow and the Kappa method.

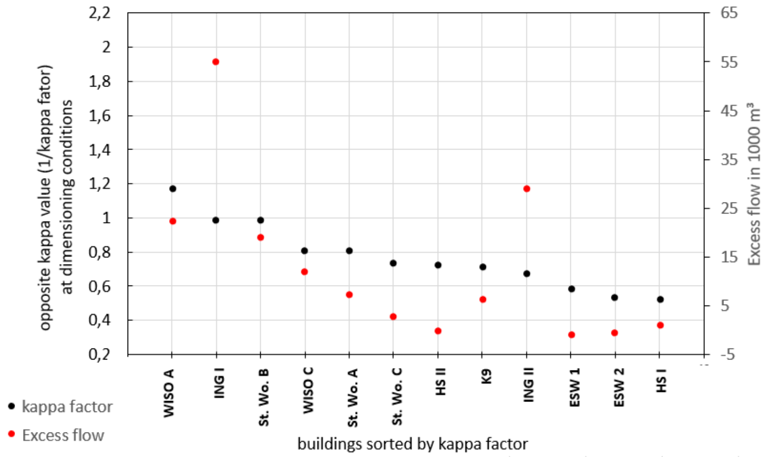

Fig. 11: Kappa ranking sorted by building and displaying the respective excess flow with opposite Kappa value (1/Kappa factor)

5. Discussion

It was shown that Kappa can be a useful approach for ranking a large building pool. However, as a newly developed method, dimensionless Kappa still requires further development and consideration. Above all, the comparability of building types M and dT is a major task for the next research steps. There are different approaches to this: Either the already described correction of the type dT buildings via the valve position in the return temperature line of the substation station, or an artificial generation of a type M building. For this purpose, the valves of the return temperature line (Fig 2) could be fully opened during the measuring phase and thus the maximum mass flow of the system artificially generated. This would result in additional losses in the heating system, but these would only be limited to the measurement period. The maximum mass flow could then be used to determine the design conditions using the simplified approach for Kappa with the heat loss coefficient (eq. 7).

The current research approach has shown in Fig. 11 that the ranking is nearly similar but does not completely match due to the size of buildings and transfer stations. The excess flow analysis approach of including the substation size could also be applicable to Kappa and could also be taken into consideration with the help of the oversizing factors of the DIN-TS-12831 analysis. As part of the research project, further building rankings were also created using the DIN/TS 12831-1 consumption analysis. There the buildings were sorted based on their oversizing factor in terms of heat demand at dimensioning condition (total heat exchanger capacity in relation to the required capacity according to DIN-TS 12831 consumption analysis). This ranking is also still in development and will be weighted, for example, by the known temperatures of the heating circuits. The Kappa method will also be compared with this ranking method in the next research step.

The dimensionless Kappa factors could be weighted by the maximum size of the substation or the actual heat demand of the buildings. This could lead to a further approximation to the excess flow method. The advantage of a validated Kappa method would be a statement about the mass flow and spreading behavior of a building at design temperature. These statements could then be determined with a small amount of measurement data or simple measurement methods and provide a very differentiated picture of a building.

In the next step, the possibility to determine a reduction potential for the building using the Kappa factors should be developed. The idea is to be able to draw conclusions on this with the help of the investigated dimensioning condition. Therefore, a connection between the primary side (substation) and the secondary side (heating circuits) must be made. Once Kappa has been finally compared and validated with the other methods, an examination of the differences and potentials of the methods could be carried out.

6. Conclusion and Outlook

Kappa is a newly introduced calculation approach for the design state of buildings in terms of their temperature spread level and mass flow based on measured data during winter. Kappa can be calculated in two different ways, via the heat loss coefficient and mass flow or via the temperature differences (eq. 5). The calculated Kappa factors can be used as a basis to rank large building pools according to existing control potentials of the substation (primary side) from the buildings point of view. The extrapolation approach, using short measurement periods warmer than the dimensioning condition to conclude the design condition, and the simplified approach for Kappa via H_{ges} and $\dot{m}_{max}$ (eq. 7) currently only works for buildings of type M (the maximum possible mass flow is provided on the primary side).

The ranking of the Kappa method and the excess flow method can be roughly compared as shown in Fig. 11. The deviations can be explained by the differences in the period of consideration of each methodical approach and the weighted heat demand in the excess flow analysis. Kappa was validated with the help of the excess flow analysis and seems reasonable for sorting the buildings. However, further in-depth investigations are required for an exact comparison and validation of the Kappa method, especially for the different building types and the extrapolation approach.

As shown in the discussion, there are two basic approaches to correcting Kappa in the future. First, the approach of correcting kappa using the available valve position data and the artificial maximum mass flow will be tested. At the same time, kappa will be compared with the ranking from the DIN-TS-12831 analysis for further validation.

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