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# Development of a user-friendly mobile app for the national level promotion of the 4th generation district heating

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**ABSTRACT**

The consumers are considered to play one of the most significant roles in the district heating transition process towards the 4th generation (4GDH). Unfortunately, the lack of information and widespread consumer ignorance of interconnections and dependencies in the district heating system (DHS) can lead to a situation where consumers are not interested in the development of the district heating system, or might even choose other heat sources. One of the possible solutions to provide information and educate consumers is a user-friendly, simplified mobile app that can show actual heat consumption structure, provide the possibility to compare the district heating supply with other heat supply solutions and provide information on how consumer behaviour affects the district heating system and how the district heating system transition towards the 4th generation will change the primary energy consumption and $CO_2$ emissions. In this article, the authors present the concept and algorithm of a DHS promo mobile app that will be used at the national level in Estonia, that will allow consumers even with an insufficient amount of data available to each apartment/building owner to receive comprehensive information about the existing DHS and analyse how DHS improvements will affect the fuel mix and consumption amount required for heat supply per consume.

***Keywords:***

Eco-feedback;
Mobile app;
Consumers;
Buildings;
4GDH;

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## 1. Introduction

The European Union has made it a priority to become the leader in the clean energy transition by committing to reduce $CO_2$ emissions by at least 40% by 2030. The main goals within this framework include improving energy efficiency, expanding renewable energy use and providing a fair deal for consumers. District heating (DH) technologies could make a sufficient contribution to the implementation of these goals. As shown in the latest overview of the existing district heating systems (DHSs), Heat Roadmap Europe 2050, 60 million (12%) citizens, 141 (28%) cities, and 287 (57%) regions across the EU member states are connected to DH networks [1]. DH is considered one of the most energy efficient and environmentally friendly ways of supplying cities with heat, compared to individual solutions. Individual heating solutions have been undergoing sufficient changes, providing consumers with energy-efficient and renewable energy based heat generation [2–4]. DH must be subjected to considerable changes to compete with other heat supply solutions, in accordance with the new conditions associated with renewable energy sources and buildings with low heat demand [5]. The concept of the 4th generation district heating (4GDH) clearly identifies the wide range of changes and trends required for the transition of the existing DHSs into the future sustainable DHSs [6]. According to this concept, future DHSs must be able to supply low temperature (<50–60 °C) for space heating and supply of domestic hot water in buildings, distribute heat through networks with low

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heat losses, increase the share of renewable energy sources and waste heat recovery in heat generation, integrate into smart energy systems and ensure proper planning. As stated in [7], there is a clear understanding of technological aspects of the 4GDH but the biggest challenge faced by the researchers is understanding the implementation of the 4GDH with an emphasis on local conditions and legislation. The various barriers encountered by the existing DHS during the transition process towards the 4th generation have been explored in a previous study [8]. Many of the barriers are related to consumers, consumer devices and consumer behaviour. First of all, low-temperature DH can be efficiently used when connected to buildings with low heat demand [9]. For successful implementation of low-temperature heat distribution systems, buildings lacking in energy efficiency must be renovated and additional refurbishment may be needed [10,11]. Another factor that can be considered an obstacle to the transition towards low-temperature heating is consumer heating devices. High radiator design temperatures as a barrier introducing lower supply and return temperatures have been discussed in many studies over the last years, for example in [12–14]. Return temperature reduction can be achieved by replacing the existing heating devices with larger radiators [13], or by optimising radiator system control via a heat exchanger [15]. Li and Svendsen have considered improving in-house substations (an instantaneous heat exchanger and a special designed DH storage tank) to be another possibility to use low-temperature DH in existing buildings [16]. Besides forced exhaust ventilation has a negative impact on DH by increasing return temperature and practically eliminating DH consumption during summer [17,18]. The domestic hot water (DHW) recirculation system in multifamily buildings is another source of high return temperatures. Introduction of consumer DHW substations for each flat with a pipe volume of up to 3 litres and an instantaneous heat exchanger [19] or installation of micro hot water storage tanks [20] can be considered as possible solutions. All of the above-mentioned solutions depend on the consumer and require strong motivation [21]. Consumers are assumed thought to play one of the most significant roles in the DH transition process towards the 4th generation. The consumers determine network growth and its parameters, and they can affect heat loss by the heat consumption density and average return temperature. One of the factors, that can serve as incentives to affect consumer behaviour is applying of DH tariff components (i.e. peak load component, flow component) [22]. DH tariffs can be successfully implemented, if consumers are well informed about DH system operating. A lack of information and widespread consumer ignorance of interconnections" and dependencies in the DHS can lead to a situation where consumers are not interested in the development of the DHS, or may even choose other heat sources. It has been proven that consumer knowledge and information availability concerning this topic are among the most important factors influencing long-term and short-term decisions [23]. In addition, there are many studies on eco-feedback that show how people's behaviour changes when they observe daily energy consumption, i.e. [24,25]. Most of these studies deal with electricity consumption [25–27] but some of them include heat consumption [28,29]. Eco-feedback is usually based on online data obtained from remote energy meters. Energy operators use it to communicate with consumers, inform them, and this helps developing the DHS. Unfortunately, remote metering is not available for all DH networks. Even if it is available for a DHS, a situation may arise where information is not available to the apartment owners, but only to the administration of the entire multifamily residential unit. In this case, a user-friendly mobile app that could inform, educate, as well as provide the consumer with approximate calculated parameters based on the real DHS (not building) input data could be offered as an option. In this article, the authors present the concept and algorithm of a DHS promo mobile app that will be used at the national level in Estonia. The second section of this paper is devoted to background information on the state of DH and the necessity of a DH promo app in Estonia. The third section describes the concept of the mobile app. The fourth section presents the application algorithm, how input-output data is received or calculated, including an example. The final section of the article includes conclusions and arguments about further development of the mobile app.

## 2. Background

There are two main reasons why consumer awareness is so important for the DH sector in Estonia. First, DH is crucial for the Estonian energy sector. The total annual heat consumption in Estonia is 6700 GWh; in 2016, 69% of that amount (4700 GWh) was supplied by DH [30]. In accordance with the amendments made to the Estonian District Heating Act in 2016, local governments have established 239 district heating regions (DHR) within the boundaries of their respective administrative territories [31]. The DHR are areas where consumer devices are provided with heat by DH in order to ensure a secure, reliable and effective heat supply. When a DHR is established, connection to the network must be mandatory for all buildings within the DHR (except for buildings who did not have DH prior to and during the time the DHR was established), and the consumers may not choose an alternative heating source (e.g., local electric heating, geothermal heating, heating stoves, etc.).

Another reason is the fact that pursuant to the proposed revised Renewable Energy Directive of the European Union, DH operators will be obliged to inform their consumers about the fuel used in heating and the efficiency of the system. In accordance with the proposed directive, consumers must have the right to withdraw from inefficient systems. The authorities and energy companies are interested in ensuring that consumers are informed about the benefits of DH, as well as the impact of consumer behaviour on DH. It has been proven that when consumers have access to comprehensible visual information on energy consumption, it prompts them to learn about their energy habits and helps address energy usage information gaps [24].

One of the best solutions to provide consumers with data obtained using remote metering. Due to the very rapid development of intelligent energy networks in recent years, smart metering has been implemented into DHSs. Smart metering can measure heat consumption, as well as exchange information on heat consumption and operation status through two-way communication between the DH operator and consumers. Using the data obtained, DH operators can offer demand site management platforms to customers via i.e. user-friendly monitors installed within dwelling [32], home heat reports, virtual customer environments, and mobile apps [33]. Advanced mobile apps can provide consumers with personalised heat consumption information; historical comparisons of heat use; energy efficiency recommendations, etc. [34].

Unfortunately, the use of smart heat meters is far behind that of smart electricity meters and remote metering is not available for every consumer [33].

Not all DH systems can provide consumers with remote metering possibility. Besides is a multifamily residential building, where most of the data provided by smart heat meters is not available to each resident, but only to the property management staff.

Calculation- and assumption-based web systems and mobile applications can be used for educational, informational and promotional purposes. A mobile app was chosen to be developed for these purposes because a comparison of a mobile app and a web-based system has shown that the mobile app is more efficient in providing eco-feedback and improved system accessibility, which increases user engagement [35]. The goal of the mobile app is, based on the limited data that is available, to provide the user with comprehensive and rather detailed information regarding heat generation and fuel consumption. This can affect consumer decisions and behaviour in both the short and long-term. This study will introduce the concept of a mobile app that is aimed at promoting DH at the national level in Estonia.

## 3. Concept

The working title for the mobile app is NutiKK (Nuti KaugKütte - Smart District heating). The main idea is to show the apartment/building owner that a particular apartment/building is a part of the DHS, show how much fuel is used to generate heat for that particular apartment, compare the current heating supply solution with other heating supply solutions available, show how DHS development (in the context of the 4GDH) would affect the primary energy consumption for that apartment and the $CO_2$ emissions from heat generated for that particular consumer.

The calculated results are presented for 3 modules: the existing district heating module, individual heating (IH) (for Mobile app development first stage natural gas based), and the 4$^{th}$ generation district heating (for the future DHS development scenario).

It was determined what parameters should be entered by the consumer and what information can be uploaded online, what business logic, including workflows will be applied to the Mobile App, and what database should be available.

Table 1 shows the input data that should be provided by the consumer/user. When the consumers are the owners of the building they receive bills with monthly building heat consumption information.

If the consumer lives in a multifamily residential building, determining the amount of heat consumed by a single apartment is more complicated. Usually, apartment owners receive bills where the cost of heat consumed by the apartment is indicated. Typically, this cost includes the cost of heat consumed by the entire building, with the communal heating cost split between the apartments. DH tariffs are public information in each DHR, so knowing the cost and tariffs, it is possible to calculate the annual heat consumption for one apartment. If the

**Table 1: Data provided by the consumer**

| | Obtained | |
|---|---|---|
| **Input data** | **Manually** | **Other** |
| Annual consumption | From bills (12 months) | Via calculations, based on the following information:<br>• Multifamily/single family<br>• Domestic hot water use<br>• Energy Efficiency class<br>• Floor area |
| Location | From the list provided | Via geographical location |
| Today's average temperature | From the list | Downloaded from the Estonian State Weather Service for various locations |

consumer doesn't have an opportunity to do so (for example, they are planning to buy a new apartment and don't have access to the bills yet), they can get the annual consumption information by indicating whether it is a multifamily or single family house, whether domestic hot water is provided by DH or not, the energy efficiency class and heating capacity of the apartment/house.

During the first stage of the mobile app development, the data obtained from the app prototype concerning annual consumption and energy efficiency class of 1239 consumers (Tallinn DH system) was analysed. Based on the collected data on annual heat consumption, a corresponding building energy efficiency class was determined.

Another input parameter is the location of the consumer. The location is used to provide information on the data, related to DHR and DH operators that supply heat to the region. In addition, depending on the location, it is possible to determine the daily heat consumption based on the outdoor temperature. The location is linked to the average outdoor temperature that is downloaded from the Estonian State Weather Service website. There are 20 temperature measuring points throughout country that can be used to obtain data online.

The mobile app's business logic manages communication between the end user interface and the database, including various groups of data. The first group of data and dependencies is needed to determine daily/monthly consumption based on annual consumption. The second group includes existing data on heat generation for DHRs of Estonia, as well as information on energy sources and consumption structure, based on the season, air temperature and heat load. The third group concerns individual heat consumption. The fourth group is associated with the DH development scenario evaluation.

As regards daily/monthly consumption determination, it will be discussed in section 4.1. The data required for 3 modules is detailed in Table 2.

By putting in the data listed in Table 1, the consumer will be able to receive the following information for all 3 modules (existing district heating, individual heating and the 4th generation district heating):

- Annual and today's heat production required by the apartment/building (kWh)(This data will be identical to heat consumption in case of using an individual boiler)
- Annual and today's primary energy consumption for heat production required by the apartment/building (kWh)
- Annual and today's fuel (by fuel type) consumption for heating the apartment (kWh and natural units)
- Annual and today's $CO_2$ emissions caused by heat generation required by the apartment/building (tonnes)
- An example of an input and output form is shown in section 4.4.

## 4. Calculation of annual and daily parameters

The description of calculations and dependencies required for the operation of the mobile application can be found below.

### 4.1. Calculation of today's consumption

The mobile app makes it possible to calculate not only the annual parameters, but also the parameters associated with today's/daily heat consumption. This is important for a better understanding of the DHS processes, because consumer can see the relationship between outdoor

**Table 2: Mobile app initial data**

| Type of Data | DH | IH | 4GDH |
|---|---|---|---|
| Annual heat production in the DHR | DH operators | — | The DHR development plan, scenario modelling |
| Annual heat loss | DH operators | — | Scenario modelling, DHR development plan, evaluation of the effects of reducing supply/return temperature |
| Annual fuel consumption, by fuel type | DH operators, assumptions | One type of fuel<br>Boiler energy efficiency<br>In case of electricity use, national PEF (Primary Energy Factor) will be taken into account | Scenario modelling by adding new energy sources, replacing existing ones, district heating regions' development plans, National Development Plan of the Energy Sector |
| Total $CO_2$ emissions | $CO_2$ emission factors | $CO_2$ emission factors | Future national $CO_2$ emission factors |
| Relative heat loss based on the outdoor temperature | DH operators, modelling/ assumption | — | DH operators, future obligations, scenario modelling/assumption |
| Fuel share based on the outdoor temperature | DH operators, in case of 2 and more fuel-based (base and peak heat plants)-calculations, modelling | — | Development scenario modelling |

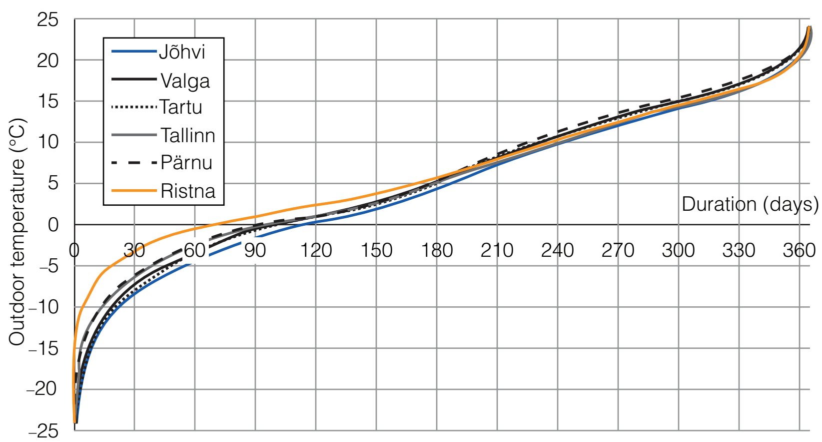


Figure 1: Outdoor temperature duration curves for Estonian regions

temperature and heat consumption. Daily heat consumption is easy to determine with the help of remote metering, but if smart metering is not available, it can be calculated based on annual consumption. This parameter is required for the 3 modules. Hourly based heat load can be calculated using daily average outdoor temperature [36]. A degree days approach is used to calculate the daily heat consumption based on the average outdoor temperature. According to research conducted by Loigu and Kõiv, there were determined six regions in Estonia with degree days diverse enough to cover the entire country [37]. Estonia's regions of the heating degree days and the centres whose outside temperatures were used to determine the heating degree days of the region, are Jõhvi, Tartu, Tallinn, Valga, Pärnu, Ristna. Figure 1 shows the number of days when the temperature was below a particular degree for that year based on yearly averages (calculated based on 30 years of metering).

It was assumed that when the average daily outdoor temperature is above 10 ˚C, there is no need for space heating in the building. The idea is that the amount of heat required for space heating per year will be consumed during the period when the outdoor temperature is below 10 ˚C.

Knowing the duration of each temperature, it is possible to calculate relative heat consumption coefficient based on the average outdoor temperature on a particular day using the Eq. (1).

$$r_{Qi} = \frac{T_b - T_i}{\sum_{i=1}^{n} (T_b - T_i) \cdot D_{T_i}} 100\% \tag{1}$$

where

$r_{Qi}$ is relative heat consumption coefficient, when average temperature per day is $T_i$

$T_i$ is average temperature per day, ˚C

$T_b$ is base temperature, ˚C

**Table 3: Base temperatures for multifamily buildings**

| *Multifamily buildings* | *Base temperature* |
|---|---|
| Average for DH consumers | 16˚C |
| Old building, no renovation (natural ventilation) | 17˚C |
| Old building, renovated (natural ventilation) | 13˚C |
| Multifamily building (forced exhaust ventilation) | 15˚C |

$D_{Ti}$ is $T_i$ duration per year;

$i$ is day number, $i = 1….n.$

Base temperature is the balance temperature at which a building doesn't need heating. Base temperature values used for further analysis are indicated in Table 3

This coefficient shows the percentage of the annual consumption value consumed per day based on the weighted average outdoor temperature for that day. The coefficient change for the average base temperature of 16˚C is shown in Figure 2a

An example of a coefficient calculated for Tallinn for various base temperatures is shown in Figure 2b

Heat consumption per day can be calculated by solving the Eq. (2)

$$Q_{Ci} = r_{Qi} Q_{cy} \tag{2}$$

where

$Q_{Ci}$ is heat consumption per day, when average outdoor temperature is $T_i$, kWh

$Q_{Cy}$ building/apartment annual heat consumption, kWh

This method for determining daily heat consumption was validated, using real heat consumption data. Daily data on heat consumption for space heating was collected via remote intelligent metering during 2017 from consumers in various DHRs (Table 4). Average outdoor

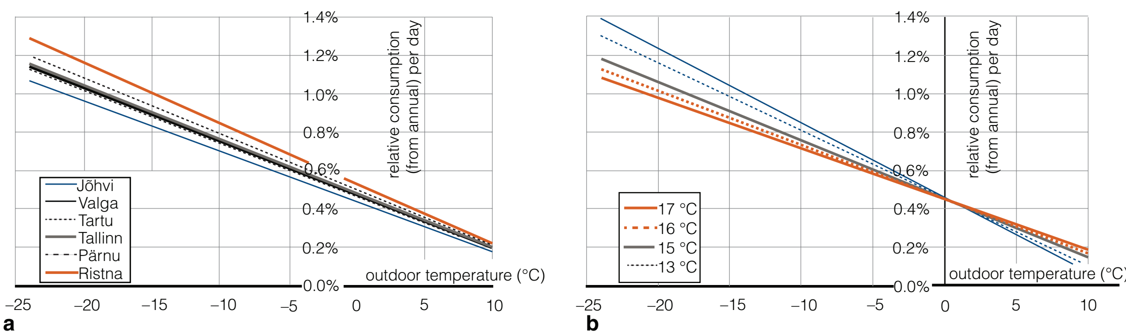


Figure 2: Coefficient $r_Q$ depending on average outdoor temperature for average base temperature 16˚C in different regions (a) and for different base temperatures in Tallinn (b)

**Table 4: Validation data collection**

| | | | |
|---|---|---|---|
| **Location** | Tallinn | Kärdla | Haapsalu |
| **Region** | Tallinn | Ristna | Pärnu |
| **Number of consumers** | 51 | 43 | 51 |
| **Consumer type** | Multifamily, non-renovated, one city district, one building type | Multifamily, both renovated and non-renovated | Multifamily, both renovated and non-renovated |

temperature for the regions was obtained from the Estonian State Weather Service.

The coefficients were calculated for all consumers by dividing daily heat consumption by annual heat consumption. The graphs used for the analysis are shown in Figures 3a, 3b, 3c.

First of all, a A correlation coefficient was calculated for each consumer to determine how the relative heat

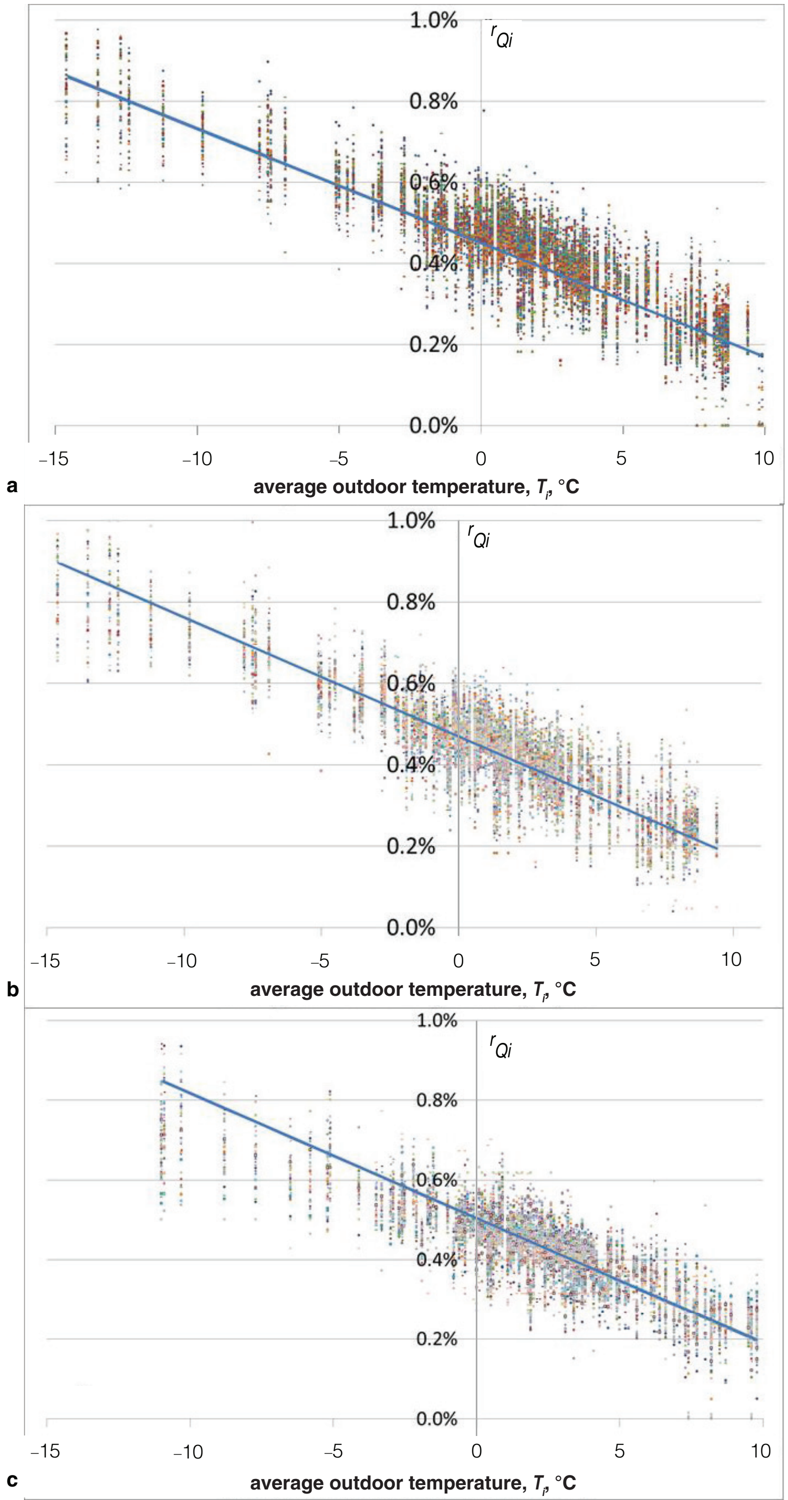


Figure 3: Relative heat consumption coefficient, calculated for consumers in Tallinn (*a*), Haapsalu (*b*), Kärdla (*c*).

coefficient correlates with the average outdoor temperature. Figures 4a, 4b, 4c show, that there is a strong correlation (>*0.5*) in almost all cases.

For Haapsalu, 6% of consumers have a weak correlation (<*0.5*), for Kärdla 11%, and for all analysed consumers in Tallinn the correlation is strong enough in all cases. This proves that daily heat consumption depends on the outdoor temperature, which is obvious. The Fisher criterion was used to test the adequacy of the model. Usually, the Fisher criterion is used to test the

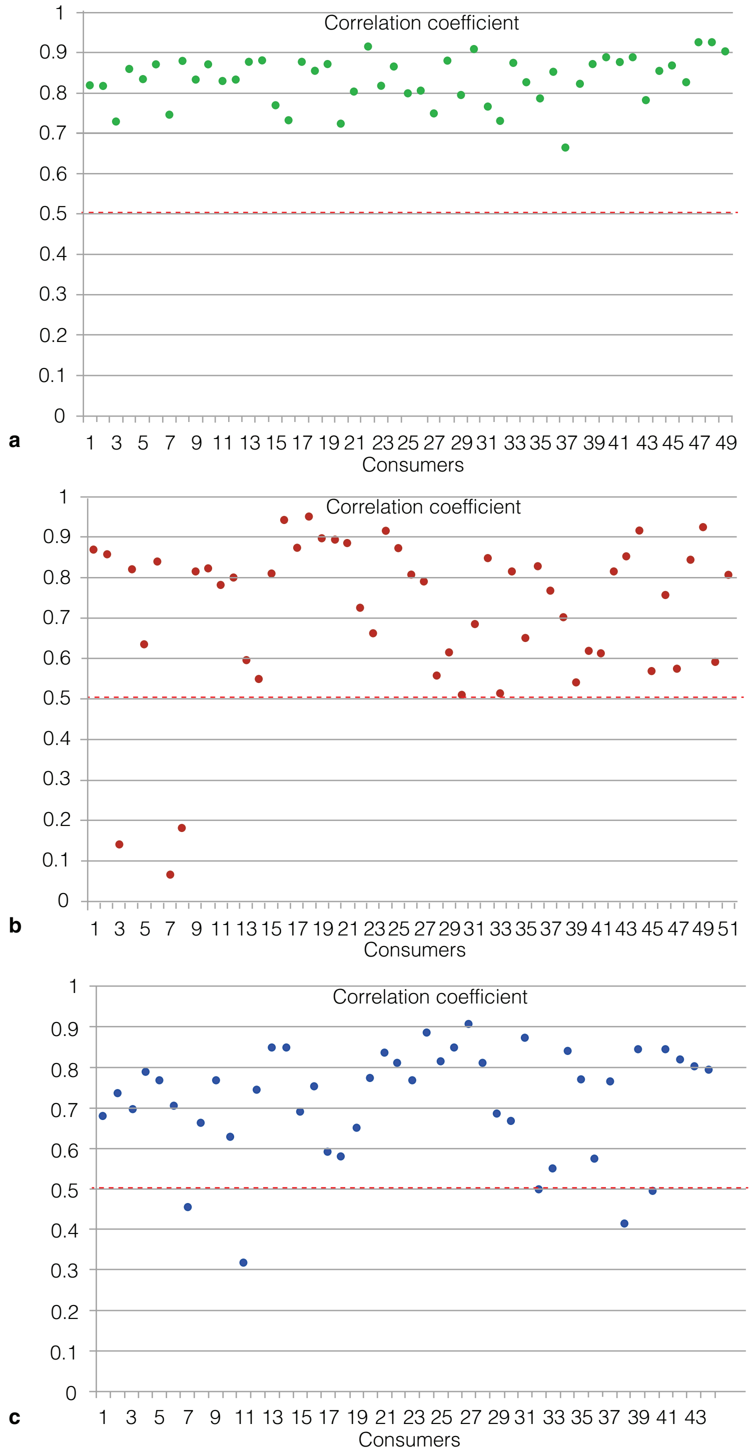


Figure 4: Correlation coefficient for $r_{Qi}$ $(T_i)$ for measurements in Tallinn (*a*), Haapsalu (*b*), Kärdla (*c*)

adequacy of regression models based on experiment data and how it was used, for example, for fuel or power consumption [38,39]. But another application of the Fisher criterion is to test whether the model is adequate to reality, which can be used for analyses. Fisher criterion has shown, that all measurements in Tallinn and Kärdla are adequate to the model for all cases, when Fisher criterion is lower than critical value. Fisher criterion analysis has shown that the selected method is not adequate and cannot be applied to only two consumers in Haapsalu. It can be explained by the fact, that people are not living in these buildings during all the year and space heating is switched on and off for some periods. These two cases have been excluded for further analysis.

The last parameter that was used to validate the proposed method is the coefficient of determination. The coefficient of determination indicates how close the calculated results are to reality or to the experimental results. The coefficient of determination is calculated by solving the Eq. (3).

$$R^2 = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y}_i)^2} \tag{3}$$

where

$R^2$ is coefficient of determination

$\hat{y}_i$ is calculated parameter $i$

$y_i$ is measured parameter $i$

$\bar{y}_i$ is average value of all measured pareters $i$

Experimental results of coefficient $r_Q$ were compared with the results calculated using various base temperatures by Eq. (1). The Figure 5 shows that for consumers in Haapsalu (Figure 5b) and Kärdla (Figure 5c) there are cases where the highest coefficient of determination is related to the base temperature of 16˚C, but for some cases it is 17˚C. There are cases where the highest coefficient of determination is related to the base temperature of 13˚C, which can be explained by the fact that that consumer's building is fully renovated. The analysis of Tallinn consumers indicates that there are no cases where the highest coefficient of determination is related to the base temperature of 15˚C (Figure 5a). This can be explained by the fact that there are no buildings with exhaust ventilation among the analysed consumers at all.

Many conclusions can be made based on the analysis of the coefficient of determination, but the key conclusion is that the base temperature could be used as another input parameter to provide more accurate results to the consumer. For the basic version of the mobile app, the average base temperature of 16˚C is used. But the pro version will include the possibility to use an additional parameter – building type parameter (according to the renovation degree and ventilation).

In case domestic hot water is used, heat consumption necessary for DHW should be added. Usually the daily consumption of hot water is the same throughout the year. According to the Method for calculation the energy performance of buildings, that is used in Estonia, the average heat consumption is 30 kWh/m$^2$/year for multi-family buildings [40]. If domestic hot water is provided by DH, the daily heat consumption is calculated using Eq. (4)

$$Q_{c\,i} = r_{Q\,i} Q_{c\,y} + \frac{30A}{365} \tag{4}$$

Where

$Q_{ci}$ is heat consumption per day, when average outdoor temperature is $T_i$, *kWh*

$A$ is floor area, m$^2$

### 4.2. Calculation of annual parameters

The annual heat generation required for heating the 1$^{st}$ and 3$^{rd}$ modules was calculated by solving Eq. (5) [41]

$$Q_{Py} = \frac{Q_{cy}}{1 - qhl} \tag{5}$$

Where

$Q_{Py}$ is annual heat generation, *kWh*

$qhl$ is relative heat loss.

It is assumed that the heat loss will be lower due to renovations and supply temperature reduction.

For the 2$^{nd}$ module, if a gas boiler is used, the heat consumed will be equal to the heat produced. The annual fuel consumption required for heating a single apartment can be calculated by solving Eq. (6)

$$Q_{f_y} = Q_{Py} \sum_j^m \frac{s_j}{n_j} \tag{6}$$

where

$Q_{f_y}$ is annual fuel consumption, required for apartment heating, kWh

$j$ is heat plant, j=1…$m$

$S_j$ is share of heat produced, by $j$ heat plant;

$\eta_j$ is energy efficiency of $j$ heat plant.

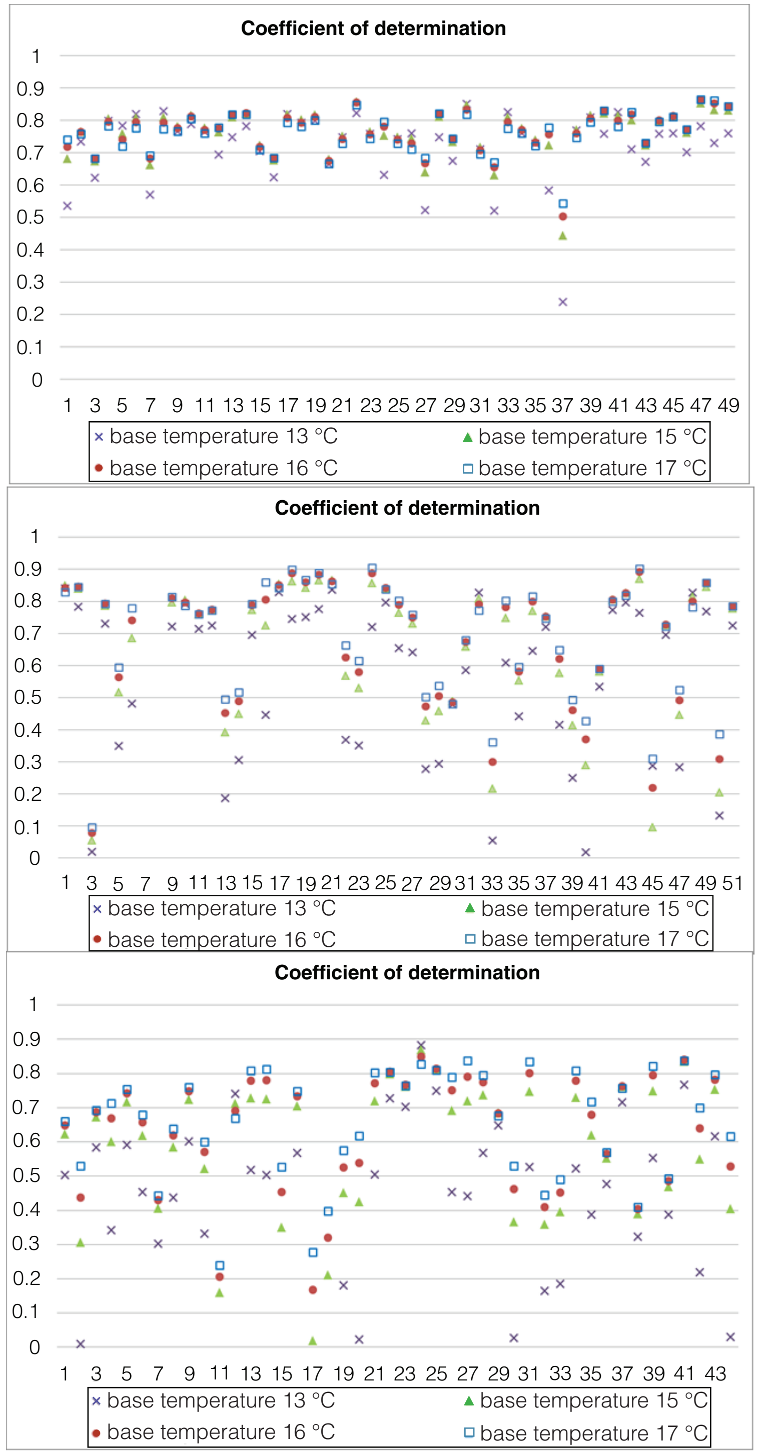


Figure 5: Coefficient of determination of the consumer analysis in Tallinn (*a*), Haapsalu (*b*), Kärdla (*c*).

Annual fuel consumption by *k* fuel type for an apartment is calculated using Eq. (7).

$$Q_{fk} = S_{f_k^y} Q_f \tag{7}$$

Where

$Q_{fk}$ is annual fuel consumption of *k* fuel type, *kWh*;

*k* is fuel type

$S_{f_k^y}$ is share of *k* fuel in annual primary fuel consumption.

Furthermore, annual fuel consumption is calculated in natural units using data about fuel lower heating value.

The following variations are available for fuel consumption in existing DHSs:

- for single-fuel DHSs, information on the energy efficiency of the heating plants should be provided;
- for DHSs with one type of fuel used for base load and a different type of fuel used for peak load, information on the heat capacity of the plants should be obtained or assumed;
- for district heating systems with a complex mix of fuel, precise information should be obtained from the district operator. However, in Estonia, there are few DHSs of this type, in fact, the most complex system is located in the Tallinn DHR, where wood chips, peat, waste, and natural gas are used for heat generation.

The same data should be provided for the 4GDH module. The data is based on district heating development plans that are available to the public. Based on the methodology presented in the paper the most optimistic scenarios will be available in the first version of the app. In the future, various possible development scenarios will be provided for consumers.

For individual heating, in the case of using a gas boiler, the energy efficiency of individual boilers should be known; however, average values can also be used.

Annual $CO_2$ emissions are calculated by solving the Eq. (8)

$$CO_{2y} = \sum_{k}^{l} Q_{fk} CO_{2k} \tag{8}$$

where

$CO_{2y}$ annual $CO_2$ emissions, $kgCO_2/kWh$

$CO_{2k}$ is emission factor for $k$ fuel type, $kgCO_2/kWh$

### 4.3. Calculation of today's parameters

As mentioned above, it is very important to provide consumer data related to daily heat consumption, since this information is not as abstract as the annual parameter, and thus more consumer-friendly. Today's heat consumption based on the average outdoor temperature per day was discussed in section 4.1., and is calculated by solving Eq. (2) when DHW is not provided by DH, and by solving Eq. (4) when the water is supplied by DH for all three modules.

Today's heat generation required for heating the 1st and 3rd modules is calculated using Eq. (9).

$$Q_{P_i} = \frac{Qc_i}{1 - qhli} \tag{9}$$

Where

$Q_{Pi}$ is today's heat generation, kWh

$qhl_i$ relative heat loss when average outdoor temperature is $T_i$

For both the first and third modules, the relative heat loss was plotted for each DHR. An example of the relationship between the relative heat loss and outdoor temperature for Tallinn is shown in Figure 6.

For the second module, today's heat consumption is equal to today's heat production.

To assess the relationship between fuel consumption and temperature, fuel share diagrams were created for the first and third modules using Eq. (10).

$$S_{k\,i} = Q_{Pi} \sum_{j}^{m} \frac{s_{kj} s_{j_i}}{n_j} \tag{10}$$

where

$S_{ki}$ share of $k$ fuel, when average outdoor temperature is $T_i$

$S_{kj}$ share of $k$ fuel in fuel consumption, by heat plant

$S_{ji}$ is share of heat produced, by $j$ heat plant when average outdoor temperature is $T_i$

Examples of diagrams for the existing and projected situations for Tallinn are shown in Figure 7a and Figure 7b.

Fuel consumption is calculated using Eq. (11)

$$Q_{f_i} = S_{k_i} Q_{P\,i} \sum_{j}^{m} \frac{s_{j_i}}{n_j} \tag{11}$$

Where

$Q_{f_i}$ is today fuel consumption, required for apartment heating, kWh

The principles for calculating annual emissions are used to calculate daily $CO_2$ emissions, and they are related to fuel consumption.

### 4.4. Example

The example used in the paper assumes that the consumer lives in one of the apartments of a multifamily residential building in the Tallinn DHR. Remote metering data is not available for the apartment owner. The only

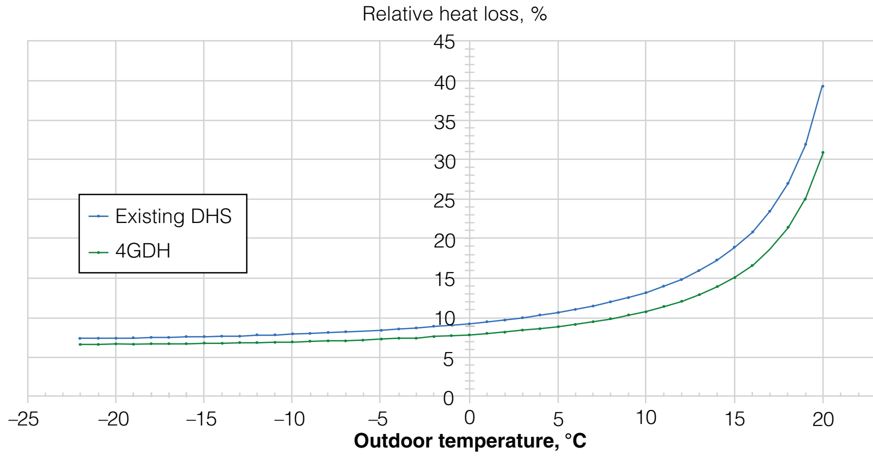


Figure 6: Relative heat loss based on outdoor temperature for existing and future DHSs in Tallinn.

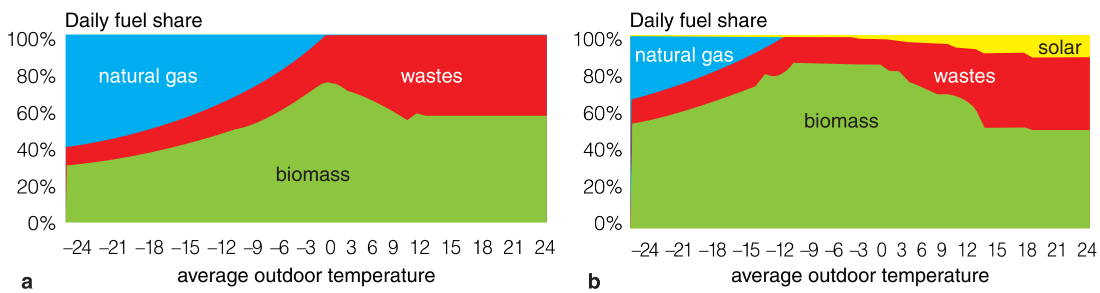


Figure 7: Fuel share by type, based on average outdoor temperature in Tallinn for existing DHS (*a*) and for 4GDH scenario (*b*)

information available for the apartment owner comes from bills where the costs of DH and domestic hot water are indicated. Summing up the cost of heating and dividing it by the heating tariffs makes it possible to determine that the heat consumption per apartment is 10450 kWh. If the consumer doesn't have access to bills, but they provide information about the efficiency class (D), building type (multifamily residential), hot water (DHW is provided by DH), and floor area (65 $m^2$), the annual consumption will amount to 10075 kWh.

For further calculations, the information obtained from the bills will be used. It is assumed that today's outdoor temperature is -5˚C.

The consumer input data and the results presented to the consumer are shown in Figure 8.

As it can be seen, even with an insufficient amount of data available to each apartment/building owner, it is possible for the consumer to receive comprehensive information about the existing DHS, compare it with individual heating solutions, and analyse how DHS improvements will affect the fuel mix and consumption amount required for heat supply per consumer. It is also possible to compare these parameters with other DHRs. The information is presented in a consumer-friendly format. As a result, the consumer will be more educated and aware of the information.

It is planned that by the end of 2019 this mobile app will be available to every resident of Estonia. At the time of writing this paper, the first prototype for 3 DHRs is undergoing testing.

## 5. Conclusions

Improving and promoting DH is very important for the successful development of the energy sector in Estonia. Due to government support, connection to DH is mandatory in almost all Estonian cities. The DH sector must be drastically improved and modified during the transition process toward the 4th generation DH. Consumers are considered to be one of the main factors associated with barriers encountered in this process. Buildings with high heat consumption, high return temperatures, non-efficient communication and cooperation between consumers and DH operators prove to be one of the most crucial

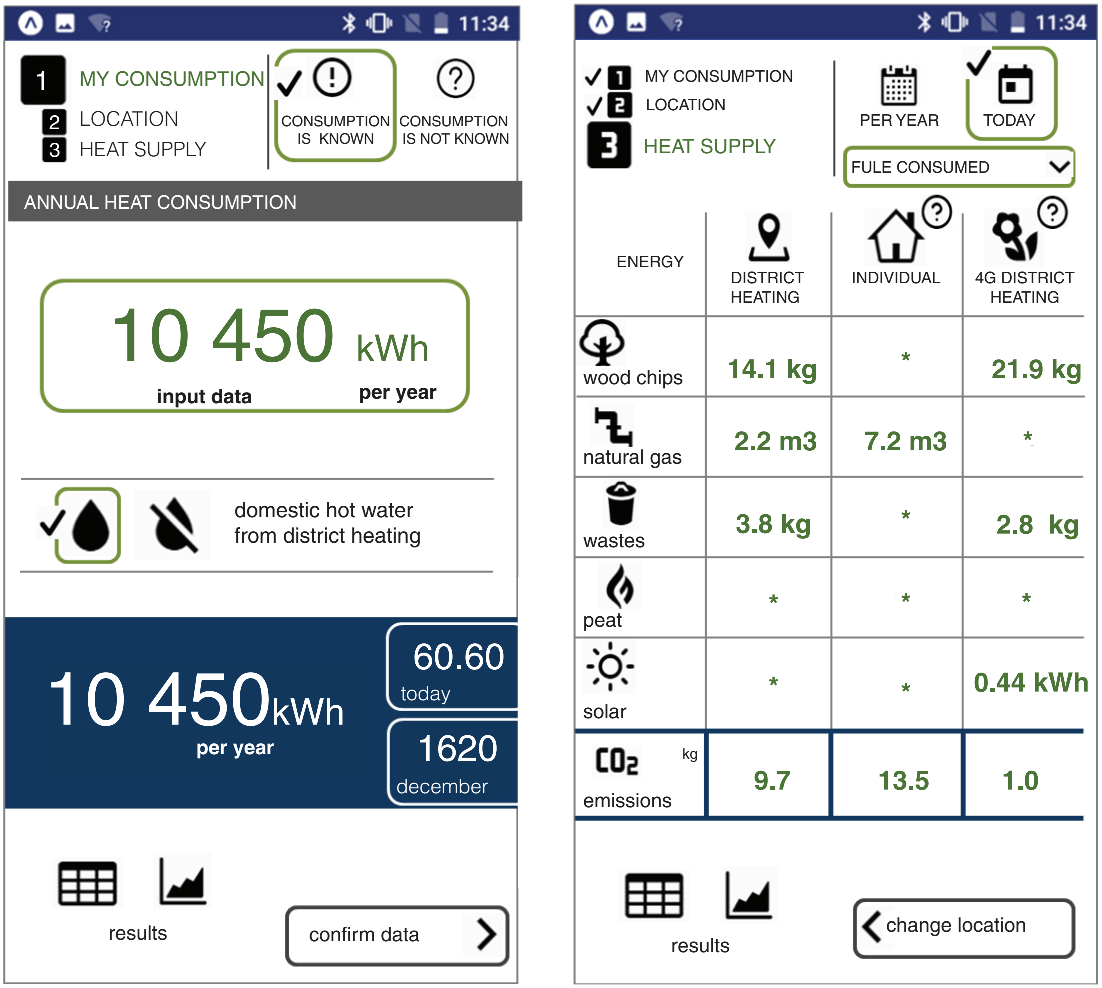


Figure 8: Example of Mobile app NutiKK input/output

barriers. The situation can be improved by affecting consumers, changing consumer behaviour and influencing consumer decision-making in the short and long-term. The mobile app can be viewed as one of the possible options to educate and inform consumers, promote the 4$^{th}$ generation DH, and improve cooperation between consumers and operators. Typically, mobile apps and web applications are based on data obtained via remote metering systems. But in the case of multifamily residential buildings, not all DHSs are equipped with remote metering systems, and even if remote metering is available, only the building administration has access to this data. The consumer won't be able to obtain accurate results using the mobile app, but they will get approximate data on DHS operation and the structure of fuels used for heat production. Presented concept and algorithm of a DHS promo mobile app or some concept components, such as data processing and presentation approach can be used for web-based or mobile-based user-friendly applications in other countries, where data regarding DH systems/utilities and outdoor temperature duration are available.

Based on the annual consumption, daily heat consumption is calculated using the degree days' approach, which varies for different regions of Estonia. By changing the base temperature for different types of buildings, it is possible to get more accurate results regarding the daily heat consumption based on the outdoor temperature. For the app to function properly, rather detailed information on the DHR should be provided. For sure there are risks that not all DH operators will be ready to cooperate and provide data, related to DHS operation. But usually, DH operators are interested in educating consumers and providing this information, because the mobile app would partially fulfil the obligation to inform consumers about the fuel used for heat generation and the efficiency of the system, in accordance with the proposed revised Renewable Energy Directive of the European Union. Besides, rather detailed information about DHS operation in Estonia is public. It is planned, that mobile app will be free of charge and available for all DH consumers in Estonia.

The mobile app may include additional features to provide more accurate and detailed information, i.e., the analysis of high return temperature impact on the DHS efficiency. The best data presentation format should be determined regarding heat production bye CHP, as well as the use of the centralised thermal energy storage within the system.

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