Applied Energy 106 (2013) 47–55

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Daily heat load variations in Swedish district heating systems

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HIGHLIGHTS

- ▶ Novel method for evaluation of daily heat load variations.
- ▶ Daily heat load variations are 3–6% of annual heat supply in Swedish district heating systems.
- ▶ Daily heat load variations is small compared to seasonal heat load variation.
- ▶ Heat storage size to eliminate daily variations is estimated to 2.5 m^3 per TJ supplied heat annual.

ARTICLE INFO

Article history:
Received 21 May 2012
Received in revised form 21 December 2012
Accepted 7 January 2013
Available online 12 February 2013

Keywords:
District heating
Daily heat load variations
Heat storage
Seasonal heat load variation
Novel method

ABSTRACT

Heat load variations in district heating systems are both seasonal and daily. Seasonal variations have mainly its origin from variations in outdoor temperature over the year. The origin of daily variations is mainly induced by social patterns due to customer social behaviours. Heat load variations cause increased costs because of increased peak heat load capacity and expensive peak fuels. Seasonal heat load variations are well-documented and analysed, but analyses of daily heat load variations are scarce. Published analyses are either case studies or models that try to predict daily heat load variations. There is a dearth of suitable assessment methods for more general analyses of existing daily load variations.

In this paper, a novel assessment method for describing daily variations is presented. It is applied on district heating systems, but the method is generic and can be applied on every kind of activity where daily variations occur. The method was developed from two basic conditions: independent of system size and no use of external parameters other than of the time series analysed. The method consists of three parameters: the annual relative daily variation that is a benchmarking parameter between systems, the relative daily variation that describes the expected heat storage size to eliminate daily variations, and the relative hourly variation that describes the loading and unloading capacity to and from the heat storage. The assessment method could be used either for design purposes or for evaluation of existing storage.

The method has been applied on 20 Swedish district heating systems ranging from small to large systems. The three parameters have been estimated for time series of hourly average heat loads for calendar years. The results show that the hourly heat load additions beyond the daily averages, vary between 3% and 6% of the annual volume of heat supplied to the network. Hereby, the daily variations are smaller than the seasonal variations, since the daily heat load additions, beyond the annual average heat load, are between 17% and 28% of the annual volume of heat supplied to the network. The size of short term heat storage to eliminate the daily heat load variations has been estimated to a heat volume corresponding to about 17% of the average daily heat supplied into the network. This conclusion can also be expressed as an average demand of 2.5 m^3 of heat storage volume per TJ of heat supplied by assuming a water temperature difference of 40 °C. The capacity for loading and unloading the storage should be equal to about half of the annual average heat load for heat supplied into the network.

1. Introduction

Heat deliveries in Swedish district heating systems are mainly used for space heating and domestic hot water preparation. Some industrial applications exist, but in many cases, the supply temperature in the district heating systems is too low to be used in industrial processes.

Heat load in district heating systems is the aggregated heat load from the heat customers connected to the district heating network and the distribution losses. The heat supply is controlled by four independent factors: the first one is the hot water taps and valves

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0306-2619
http://dx.doi.org/10.1016/j.apenergy.2013.01.030

in radiators and ventilation air heating systems which control the heat demand. The second one is the control valves in the primary side of the substation which keeps constant temperature of hot water and supply temperature to heating systems depending on outdoor temperature by controlling the primary flow. The third one is differential pressure control on the primary side where the differential pressure has to be kept at a set point at the periphery of the network. The fourth one is the supply temperature on the primary side depending on outdoor temperature, i.e. it is the heat users that are in control of the heat demand. The district heating operators deliver a possibility for a proper heat supply. Since the heat load at the customers' end is not constant, heat load variation at the customers results in heat load variation in the heat plant.

The heat demand from a district heating system is fulfilled by a water mass flow and a temperature difference, i.e. there are two ways to satisfy changes in heat demand: changing the flow through all district heating sub-stations or changing the temperature difference between the supply and return pipes. If a customer increases the heat demand by increasing the mass flow, the increased heat demand propagates to the heat plant by the speed of sound in water, i.e. approximately 1000 m/s. But, if the customers increase the heat demand by increasing the temperature difference, the heat demand propagates to the heat plant with the flow rate of the water in the district heating pipes, i.e. 1–3 m/s. Hence, changes in heat demand, due to changes in flow rate, propagate to the heat plant in a few seconds, while heat demand due to changes in temperature difference will propagate to the heat plant in minutes for the customers close to the heat plant and in hours for customers at the periphery of the district heating network, at least in large district heating systems. This is called geographical diversity. For further information about district heating system functions, see [1].

Large variations in the outdoor temperature between summer and winter generate large heat load variations over the year, seasonal heat load variations, but there are also heat load variations between, and within single days: daily heat load variations.

In published analyses, several papers with case studies or suggestions to predict or control the heat load in the heat plant can be found.

In a model of heat load forecasting it is stated that especially the fast changes in heat load is difficult to predict [2]. Heat load prediction would make it possible to take action in advance. A prediction by simulating a repetitive heat load pattern is presented in [3] and [4]. A support for actions in the district heating network is described in [5], where a method to predict how a temperature front propagates in a district heating network. By using multi-agent systems, where the substations and the heat plant can communicate with one another, a possibility to control each part of the system, including the substations, and optimise the whole system would be possible [6,7]. One possibility with this method would be if there are deficits of heat, the existing heat could be supplied to all heat customers instead of only to the customer closest to the heat plant. A second possibility would be to use buildings as heat storage as described in [8] and thereby be able to use the entire district heating system, including the connected buildings, as heat storage. Advantages of daily heat load variation elimination are described in [9]. The possibility of optimising and reducing peak loads i.e. decreasing the daily heat load variation is described in [10] by using heat meter measures at the customers as input information.

It is obvious that daily variations can cause load problems. Various actions are being taken in order to decrease daily heat load variations, but there is a dearth of suitable assessment methods for general analyses of how to quantify daily heat load variations in district heating systems. In this paper a generic method independent of system size and parameters other than the time series analysed is described. The method could be used for either design purposes or for an evaluation of existing storage units. This method will then be applied on 20 Swedish district heating systems. More knowledge about heat load variations is needed in order to create smarter heat grids in the future.

1.1. Seasonal heat load variation

Seasonal heat load variation is well-known and obvious. It mainly depends on large differences in outdoor temperatures between winter and summer, combined with the demand to have a more or less constant temperature inside the building envelopes.

Heat loads can be split into two categories: physical heat load and social heat load. Heat loads that depend on physical conditions, like temperature differences and degrees of insulation, is called physical heat load. Distribution losses are also physical losses since they depend on the temperature difference between the district heating water and the surrounding temperature of the district heating pipes. Other physical heat loads is the influence of wind and solar radiation. Wind increases the heat demand because of infiltration. Warm air is replaced with cold air that has to be heated. Solar radiation decreases the demand of external heat in two ways. It increases the temperature of the exposed outer walls and thereby decreases the flow of heat from the inside of the building through the walls and windows acting like a greenhouse where solar radiation is let into the building, but the reflected long-wave radiation cannot pass throughout the window panes. Both wind and solar radiation increase the seasonal heat load variations. The windiest parts of the year are when it is cold outside and solar radiation is the most intense during the warm parts of the year.

Social heat load depends on the social behaviour of the tenants. A typical social heat load is domestic hot water preparation. This preparation is an important factor for daily heat load variation as will be described hereafter. There is a seasonal component in hot water preparation as well. In winter, people spend more time indoors and thereby use more hot water. In summer and during holidays, some people leave their urban dwellings temporarily and do not use hot water at all. Hence, domestic hot water preparation increases the seasonal heat load variation. One part of the physical heat load in domestic hot water is that the temperature of the incoming water changes during the year. This is especially true in cities where fresh water is taken from a surface water reservoir. In this case, the seasonal heat load variation will increase since the incoming cold water is colder in winter than in summer. Further description of seasonal heat load variations in district heating system can be found in [11].

In Fig. 1, a typical seasonal heat load pattern can be observed with high heat loads during winter and low heat loads during summer.

1.2. Daily heat load variation

Heat demands in a district heating system are generated at the customers' end. These heat demands are not constant during the day. Even though district heating systems even out daily heat load variations as a result of geographical diversity and also that heat load peaks at the customers' end do not occur at the same moment, there are still daily heat load variations. There are several reasons for daily heat load variations in district heating systems. Most of them are social heat demands. When a person chooses to turn on a hot water tap to wash their hands it will result in an increased heat demand in the building that will reach the heat supply plant through the district heating network. Social heat demands are heat demands caused by both individual and collective social behaviours. One example of individual social behaviour is hot water

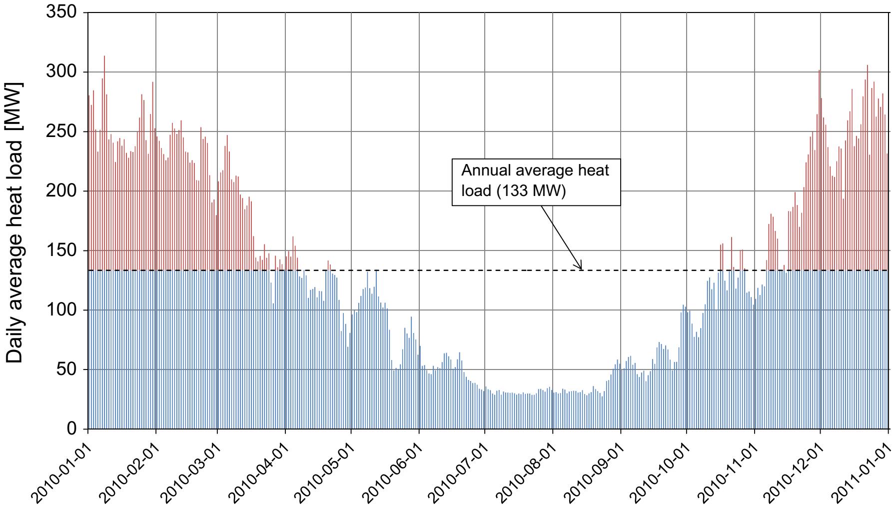

Fig. 1. Seasonal heat load variation illustrated by the daily average heat load during a year in a district heating systems with an annual heat supply of about 4400 TJ.

consumption. Harmonised working hours is an example of collective social behaviour. In offices and schools, where no people are present in the buildings at nights and weekends, no or lower ventilation rates can be applied. Hereby, time clock operation of ventilation should be used in all ventilated spaces that are not in use 24 h a day. This action will decrease the heat demand, but it will also create daily heat load variations.

In residential dwellings, tenants normally sleep at night and do not use domestic hot water, but when they wake up, the first thing they do is to go to the bathroom and turn on the hot water tap. This behaviour will increase the heat demand and create daily heat load variations. The same thing will occur when people come home from work in the evening and start using hot water. Night setback mode is still available in heating control systems; even though it does not decrease the total heat use it increases the heat load variation in a way close to time clock operation of ventilation [12].

In domestic hot water preparation, two different methods are used: direct hot water preparation and hot water storage. In direct preparation, the hot water is heated momentarily at usage in a heat exchanger, which has the capacity to fulfil all peak demands directly. The hot water storage method has a heat exchanger with a lower capacity for loading the storage. At peak demands, the storage of domestic hot water is unloaded. When stored hot water is used, the hot water is replaced with cold water. When using direct preparation, the preparation coincides with the use, creating some daily heat load variations. When hot water storage is used, the daily load variations will not be so pronounced.

There are also physical heat loads that generate daily heat load variations. The fact that night-time outdoor temperatures are normally lower than daytime temperatures generates daily heat load variations. Solar radiation also decreases the daytime heat loads. A typical heat load pattern can be observed in Fig. 2. Three characteristics can be identified:

1. Two peaks during a day, one heat power peak in the morning and one peak in the afternoon.
2. The influence of large differences in outdoor temperature during night and day in spring and autumn gives a significant dip in the heat load in the middle of the day.
3. No or small weekly heat load variations, i.e. variations between different days of the week.

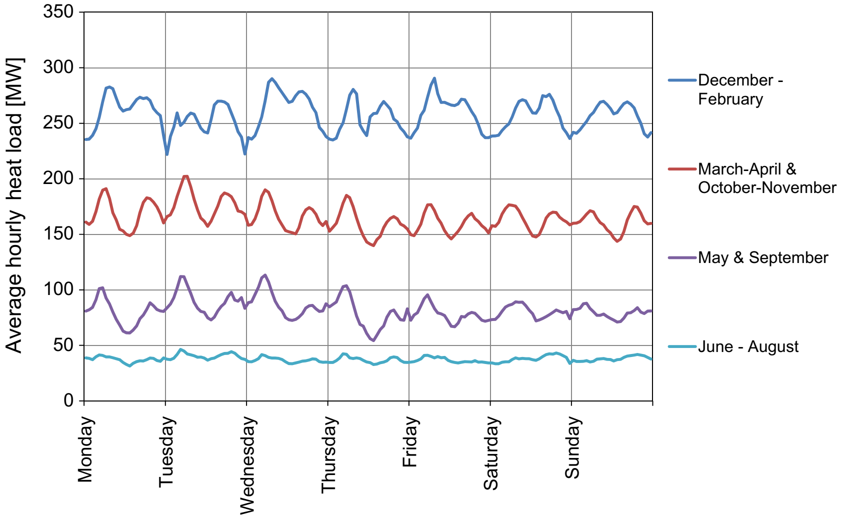

Fig. 2. Daily heat load variation illustrated by the aggregated average hourly heat load during weekdays for four different seasons in a district heating systems with an annual heat supply of about 4400 TJ.

1.3. Consequences of heat load variation

Heat load variations, both seasonal and daily, generate increased costs in district heating systems. Heat plants must always generate and supply the customer's aggregated heat power to the district heating network. A problem in district heating systems is that if not enough heat power is supplied to the network it does not affect all customers equally, but only the peripheral customer in the district heating network. If the heat supply to the district heating network is less than the heat demand, the customer closest to the heat plant will not notice any lack of heat, but customers at the periphery of the district heating network will not get any or very little heat. The reason for this is that the differential pressure between supply and return pipe is highest close to the heat plant and then decreases at the periphery of the district heating network. At the customers' end, it is the differential pressure between supply and return pipe that drives the flow through the district heating substation. The differential pressure control is managed by the main distribution pumps in the district heating network and there are normally no local pumps at the customers' buildings. Therefore the customers closest to the heat plant will have the highest differential pressure and use it to increase the flow of district heating water through the district heating substations to increase the heat power while the customers at the periphery will suffer from a lack of heat. As a consequence of this fact, most of the time an overcapacity of heat power has to be available to secure the heat supply to all heat customers.

One way to handle the variation, and the one that is mostly used, is to have heat storages. In the 1980s, investigations and some tests were performed to have seasonal storages to store heat in summer to be used in winter, but so far no competitive technology exists [13,14]. The cost of the seasonal heat storage is too large compared to alternative heat costs. The only seasonal heat storage in operation known by the authors is located in Marstal, Denmark, where heat storage for a solar district heating system is in use [15].

For daily variations though, there are a number of possible methods to decrease peak load capacity and thereby also reduce the heat load capacity need in the district heating systems. Often it is a part of the optimisation of heat storage where other influences like increased electricity generation and maximization of industrial excess heat are included. Various examples of heat storage sizing are presented in [16] and [17]. It is stated in [17] that the optimal heat storage is strongly connected to the relative amount of relative peak load, i.e. how large the heat load variation is. The district heating network contains a large mass of water. By increasing the supply temperature above what is necessary for the present heat supply, heat can be stored in the network. Another solution is to use heavy buildings connected to the district heating network as heat storage [8]. In heavy buildings with time constants of a few hundred hours, it would be possible to increase the heat supply during low load in the district heating system and decrease the heat supply during high load without a reduction of the customers' heat comfort.

If daily heat load variations could be eliminated in district heating systems, it would make the operation of the district heating system less costly and more competitive. There would be several advantages in the operation such as:

- Less use of expensive peak load power where often expensive fuels are used.
- Less need for peak load power capacity.
- Less need for electricity for district heating network pumping.
- Improved utilisation of industrial excess heat.
- Easier to optimise the operation that leads to higher conversion efficiencies.
- Less need for maintenance because of a smoother operation of the plants.

Before water accumulators are built or devices installed to store heat in the district heating network or customers' buildings, the heat load variations and existing storages need to be characterised and quantified. Even though daily heat load variations are often mentioned as something that is desirable to eliminate, no work has been found that more closely describe nor quantify daily heat load variations.

In this paper a novel assessment method to describe daily variations is presented. It is applied on district heating systems but is generic and could be applied on every kind of activity where daily variations occur. Daily heat load variations in district heating systems can be characterised by giving answers to these three questions:

- Which magnitude has the daily heat load variation in a district heating system?
- Which heat storage volume is needed in order to eliminate the daily heat load variations?
- Which capacity is needed for loading and unloading this heat storage?

2. Methods

The requirements when developing the method described below were to have a generic method independent of system size and parameters other than the analysed time series.

Time series of heat supplied into 20 Swedish district heating networks have been collected in order to analyse the daily heat load variations. The resolution in these time series is 1 h, giving 8760 hourly average heat load values for 1 year for each system.

In order to describe the daily heat load variations, three different variables have been defined:

1. Annual relative daily variation (G_a).
2. Relative daily variation (G_d).
3. Relative hourly variation (G_h).

To be able to compare daily variations with seasonal variations, a fourth variable for seasonal heat load variations has been defined:

1. Annual relative seasonal variation (D_a).

The annual relative daily variation, G_a, is a measure of the daily heat load variation during a year. The value itself expresses the annual proportion of the sum of all heat loads supplied over each daily average heat load over 1 year. It is used to compare different district heating systems with each other.

The relative daily variation, G_d, is a measure of the daily heat load variation for a single day. This variable expresses how much heat that needs to be stored each day in order to eliminate each daily heat load variation. A heat storage that stores as much heat as the highest value of the year will give the possibility of eliminating all daily heat load variations. The sum of all relative daily variations divided by 365 becomes the annual relative daily variation.

The relative hourly variation, G_h, is the daily variation each hour. It expresses the heat transport capacity for loading and unloading the heat storage each hour. In order to be able to eliminate all daily heat load variations, a heat transport capacity to and from the heat storage equal to the highest relative hourly variation is needed.

The annual relative seasonal variation, D_a, is a measure of the seasonal heat load variation during a year. The value itself expresses the sum of all daily average heat loads supplied over the annual average heat load in 1 year.

All four variables are relative variables related to the annual average heat load multiplied by the number of hours related to the variable: 8760 h for the annual relative daily variation, and the annual relative seasonal variation, 24 h for the relative daily variation, and 1 h for the relative hourly variation. The four variables are determined from hourly average heat load (P_h), daily average heat load (P_d) and annual average heat load (P_a).

2.1. Annual relative daily variation (G_a)

Annual relative daily variation is defined as:

$$G_a = \frac{\frac{1}{2}\sum_{h=1,d=1}^{8760,365}|P_h - P_d|}{P_a \cdot 8760} \cdot 100\ (\%) \tag{1}$$

where P_h is hourly average heat load (W); P_d is daily average heat load (W) and P_a is annual average heat load (W).

The annual relative variation is the accumulated positive difference between the hourly average heat loads and the daily average heat loads during a year divided by the annual average heat load and the number of hours during 1 year. The division with the annual average heat load is introduced in order to get a measure independent of system size. The annual relative daily variation is expressed with one single value per system and year. The value itself expresses the annual proportion of all heat loads supplied over the daily average heat loads. These annual values can be used to compare the daily heat load variations from various district heating systems.

2.2. Relative daily variation (G_d)

Relative daily variation is defined as:

$$G_d = \frac{\frac{1}{2}\sum_{h=1}^{24}|P_h - P_d|}{P_a \cdot 24} \cdot 100\ (\%) \tag{2}$$

The relative daily variation is the accumulated positive difference between the hourly average heat load and the daily average heat load divided by the annual average heat load and the number of hours during a day. The relative daily variation is expressed with 365 values per system and year.

Relative daily variation is determined for each day and is a variable that quantifies the amount of heat that is diverted from the daily average heat load. A heat storage size equal to the largest value of relative daily variation during a year is enough to eliminate all daily variations over the year.

2.3. Relative hourly variation (G_h)

Relative hourly variation is defined as:

$$G_h = \frac{|P_h - P_d|}{P_a} \cdot 100\ (\%) \tag{3}$$

The relative hourly variation is the absolute difference between the hourly average heat load and the daily average heat load divided by the annual average heat load. The relative hourly variation is expressed with 8760 values per system and year.

The relative hourly variation is the heat power capacity for loading and unloading the heat storage to eliminate the daily variations. A heat power capacity of loading and unloading the heat storage equal to the largest value of relative hourly variation is the amount of heat load capacity to eliminate daily heat load variations over the year.

2.4. Annual relative seasonal variation (D_a)

The annual relative seasonal variation is defined as:

$$D_a = \frac{\frac{1}{2}\sum_{d=1}^{365}|P_d - P_a|}{P_a \cdot 8760} \cdot 100\ (\%) \tag{4}$$

The annual relative seasonal variation is the accumulated positive difference between the daily average heat loads and the annual average heat load during a year divided by the annual average heat load and the number of hours during 1 year. The division with the annual average heat load is introduced in order to get a measure independent of system size. The annual relative seasonal variation is expressed with one single value per system and year. The value itself expresses the annual proportion of all heat loads supplied over the annual average heat load.

3. Gathered data

The data sets that are used to determine the daily heat load variations have been collected from 20 district heating systems in Sweden. It is the heat supply to the district heating network, i.e. distribution losses are included in the measuring values. The sizes of the analysed district heating systems are between 32 TJ and 13,300 TJ heat supplied annually to the networks.

The data sets consist of 1-year series from 1st of January to 31st of December, i.e. 8760 values each year. The unit of the values from the meter reading system is MW h/h. Most of the data sets are from 2008 and 2009, but a few are from the years 2004–2007.

For most district heating systems a 1-year data set is collected, but for two district heating systems 5 and 6 years of data sets respectively are collected. This multiyear data is used to analyse the daily heat load variation between different years, later presented in the result section.

The hourly average heat load is often called heat power, but it is actually delivered energy during 1 h. The heat is continuously measured every whole hour. The present meter value minus the preceding meter value is the hourly value for the present hour.

District heating systems with an annual heat supply of more than 700 TJ are normally measured hourly. For district heating networks with an annual heat supply of less than 350 TJ, the number of systems that measure hourly is fast decreasing.

For most of the data series, no or only single values are missing, but in a few cases, values in the annual data series are not complete. For single values and up to five values in a row of missing values are reconstructed by interpolation. Since district heating network systems are thermally slow, changes in the heat power are also slow. If there are more than five values missing, an analysis of the day before and the day after was made to see if there is a typical heat load pattern. Sometimes it is possible to interpolate more than five values. If the pattern does not show a linear behaviour the values from either the day before or the day after are copied. Which day that is used depends on which of the days that looks most like the day with the incomplete data series. The amounts of corrected values are less than one per thousand and have thereby no impact on the results.

4. Results

4.1. Annual relative daily variation

As can be observed in Fig. 3, the annual relative daily variation does not differ much between the different district heating systems. In the studied district heating systems, the annual relative daily variations are between 2.6% and 5.7% of the annual volume of heat supplied into the district heating networks with a mean value of 4.5%. It is only two large systems that have somewhat lower annual relative daily variation.

If the same method is used for seasonal heat load variation as for daily variation the annual relative seasonal variation is in average 24% with a spread of between 17% and 28%. The annual relative seasonal variation for system in Fig. 1 is 27% which corresponds to the area over the mean value divided by the total annual heat supply.

Compared to the seasonal heat load variation, daily heat load variation is very low. The reason for this is that the main part of heat demand is caused by the difference between outdoor and indoor temperatures.

An expected result would be that large district heating systems have smaller relative daily variations (G_a) than small district heating systems. There are two reasons for that:

1. In large district heating networks, customers are geographically spread over different pipe distances from the heat supply plants. Hereby, the water in the return pipe arrives to the heat supply plants at different times compared to when the return water leaves each substation. This is called geographical diversity in the district heating network and should reduce the daily heat load variation.
2. In large district heating networks, you would expect that the operators are more actively involved in the heat distribution network with respect to temporary heat storage in the district heating network.

But as can be observed in Fig. 3 it is not as simple as that. The daily heat load variation is more or less the same for most district heating systems. For district heating systems larger than 4000 TJ annually delivered heat seems to have smaller daily heat load variations.

The annual relative daily variation for of the Swedish total electricity use in 2008 was as a comparison 4.5%, with a total delivered amount of electricity of 497 PJ [18]. In other words, about the same size of daily heat load variation as the district heating systems. One district cooling system with 72 TJ of annually supplied cold has

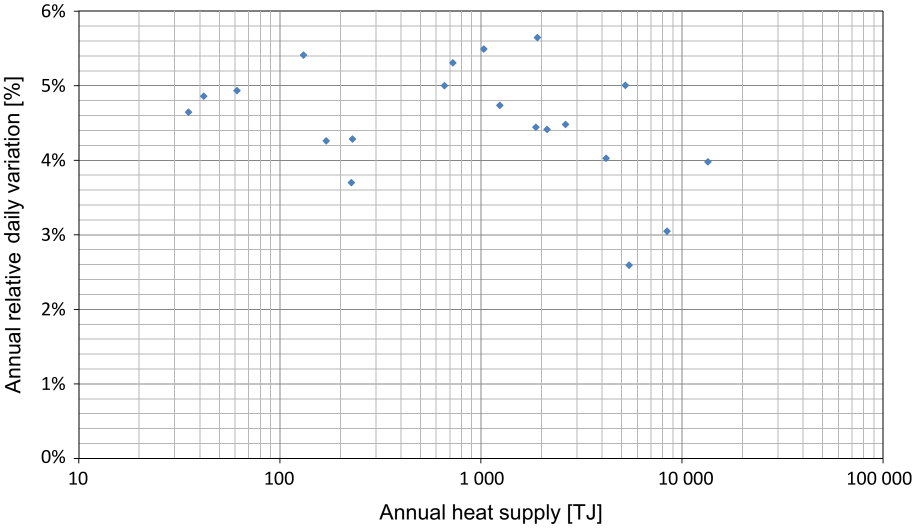

Fig. 3. Annual relative daily variation for the 20 Swedish district heating systems analysed.

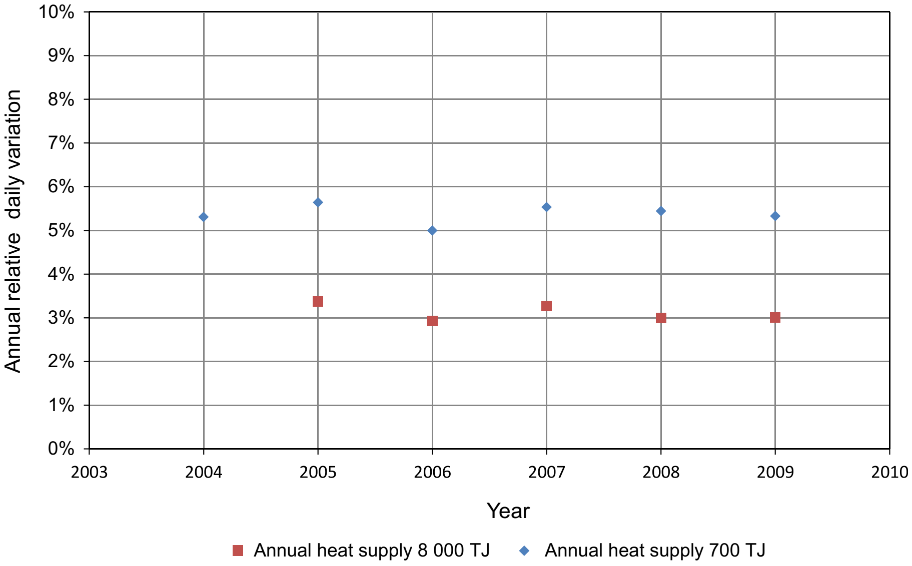

Fig. 4. Annual relative daily variation over a number of years for two Swedish district heating systems with an annual heat supply of about 700 TJ and 8000 TJ respectively.

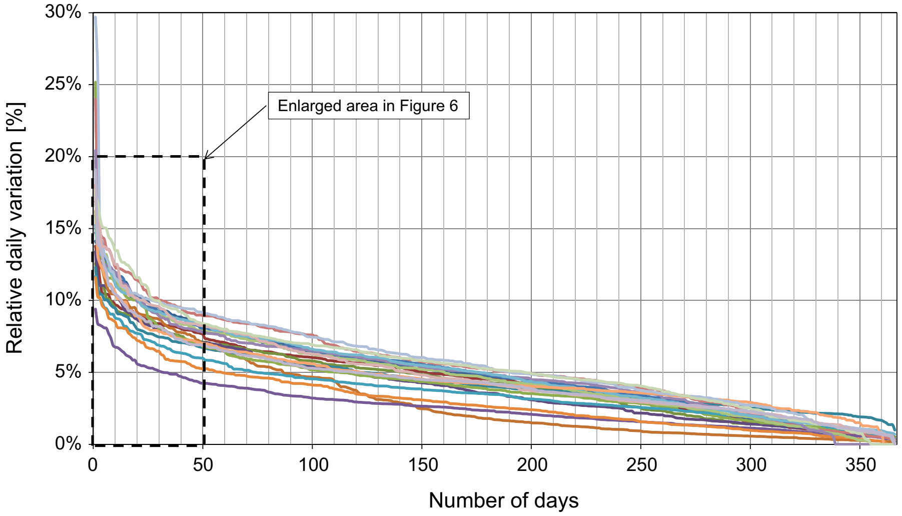

Fig. 5. Relative daily variation for the 20 Swedish district heating systems analysed.

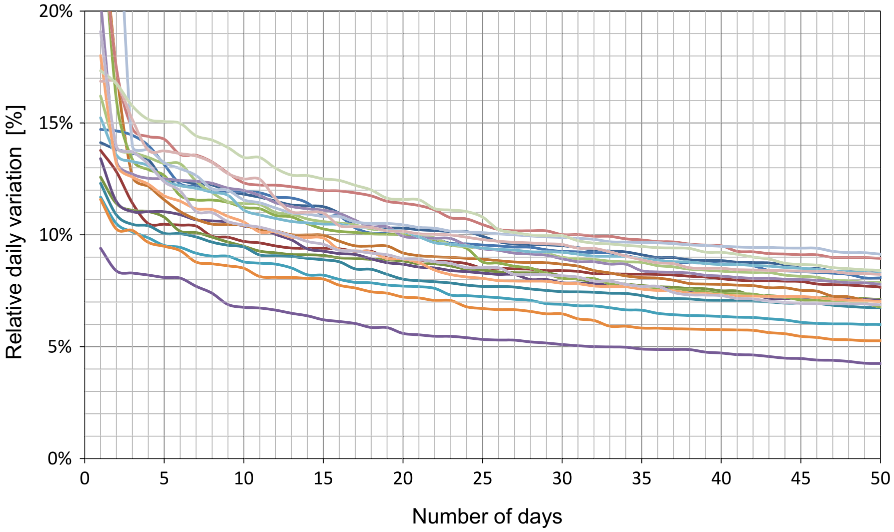

Fig. 6. Enlarged part of Fig. 5 showing the peak parts of the relative daily variation.

also been evaluated. The annual relative variation in this system was 8.6%, which is twice the daily variation estimated for the district heating networks.

To investigate if the annual relative daily variation differs from 1 year to another, multiyear data series were gathered for two district heating systems. Both district heating systems are located in the south of Sweden, one with an annual heat supply of 700 TJ and one with an annual heat supply of 8000 TJ, Fig. 4. The difference is 0.44% units for the larger system and 0.65% units for the smaller system; in other words, the difference in annual relative daily variations between different years is small.

4.2. Relative daily variations

In Fig. 5, the relative daily variation is calculated for each day during the year and sorted by magnitude for the 20 Swedish district heating systems analysed. Fig. 6 contains the same information, but focuses on the highest values obtained.

Maximum value for the largest daily heat load variation is 30% of daily average heat supply and minimum value is 9%. Average value is 17%. This corresponds to 0.05% of the annual heat supplied. In the absence of an economic evaluation the 99th percentile could be used as design condition to exclude extreme values. For the 99th percentile, corresponding to 3.65 days, the maximum value has decreased to 15%, minimum value to 8%, and average value to 12%.

With an effective heat storage size corresponding to 12% of daily average heat load, almost all daily heat load variations are possible to eliminate.

The conclusion above can also be used for estimating the specific demand of a heat storage volume. For each TJ of annual heat supplied, the annual average heat load becomes 32 kW, so with 3.6 h of operation (15% of 24 h), this will give a demand for storing 410 MJ. Assuming a 40 °C temperature difference for the heat storage, the requested water volume becomes almost 2.5 m^3 for each TJ of heat supplied during a year. The corresponding heat storage volume for the relative daily variation of 12% is 2 m^3/TJ of annually supplied heat.

A brief study has been performed for existing heat storages in Swedish district heating systems. The result is that the sizes of heat storage installed are between 4% and 250% with an average of 47% of average daily supplied heat; i.e. the average heat storage in Swedish district heating systems is three times larger than the heat

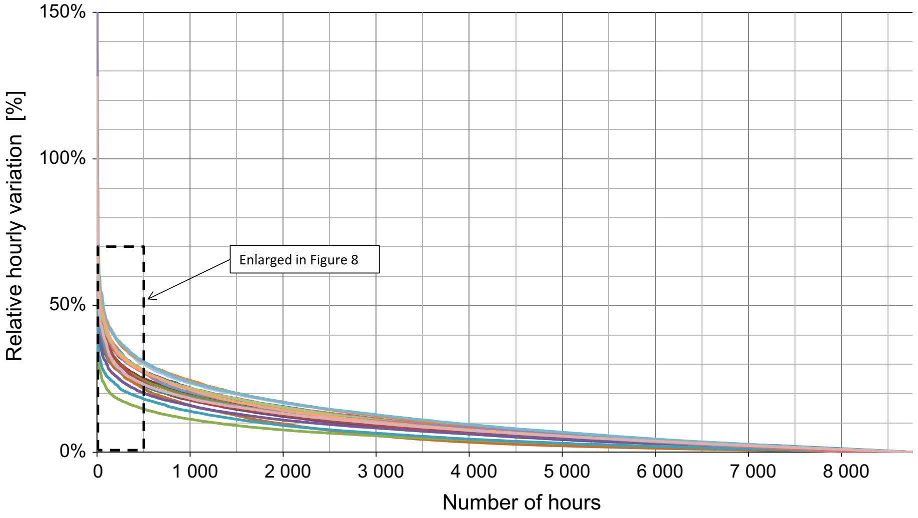

Fig. 7. Relative hourly variation for the 20 Swedish district heating systems analysed.

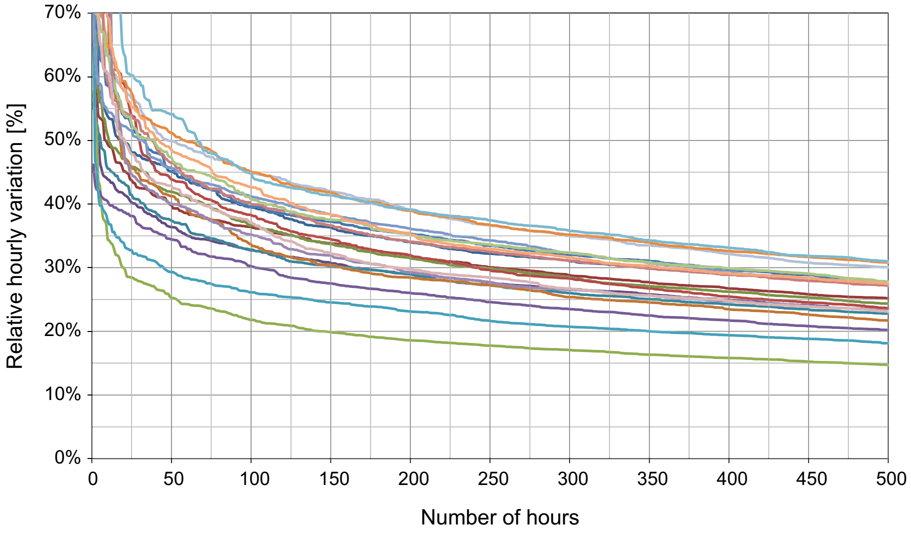

Fig. 8. Enlarged part of Fig. 7 showing the peak parts of the relative hourly variation.

storage size demand to eliminate daily heat load variations. This indicates that heat storages are used to do more than eliminate daily heat load variations.

4.3. Relative hourly variation

In Fig. 7, the relative hourly variation is calculated for each hour over a year. Note that it is the absolute value, i.e. it can be either loading or unloading capacity. Fig. 8 contains the same information but magnified for the high values.

Highest value of all 20 district heating systems is 196% of annual average heat load and the lowest is 46%. Average value is 91%. With the same reason as for relative daily variations, i.e. absence of economical evaluation, the 99th percentile could be used as sizing condition to exclude extreme values. In the 99th percentile the max value has decreased to 47%, min has decreased to 23% and the average value to 38%.

On the analogy of relative daily variation a specific heat loading and unloading capacity for the heat storage to eliminate heat load variations can be quantified. An hourly relative variation of 38% results in a loading/unloading capacity of 12 kW for each TJ supplied.

5. Conclusions

A novel assessment method for describing daily variations is presented. It is a generic method independent of system size and other parameters than the analysed time series. Three parameters have been defined: annual relative daily variation, which is a benchmarking parameter between systems; relative daily variation, that describes the expected storage size to eliminate daily variations; and relative hourly variation, which describes the load and unload capacity of the storage. The parameters can be used for at least two purposes: design and evaluation of existing storages.

This novel method is used to perform an analysis of 20 Swedish district heating systems. The average annual relative variation has been estimated to 4.5% for the 20 district heating systems evaluated, while the average annual relative seasonal variation is 24%. Thus, the magnitude of annual relative daily variation is small compared to annual heat supplied and compared to seasonal heat load variations.

The size of heat storage in order to eliminate daily heat load variations is in the magnitude of 17% of average daily heat supplied or 0.05% of annual heat supplied. The size of existing heat storages installed in district heating systems in Sweden are in average three times greater than the necessary size in order to eliminate daily heat load variations. This indicates that heat storages are used for more services than elimination of daily heat load variations. Two examples could be storage as a reserve between days or to increase electrical power generation at high prices.

Hourly heat load variation is just below 40% of the annual average heat load. This corresponds to a loading and unloading time of 7 h from full to empty or empty to full heat storage.

Two possible direction of further work would be: first, to analyse district heating systems outside Sweden using other control strategies and/or other daily social patterns; and second, to better understand daily variations in district heating systems by analysing corresponding variations for the customer substations in order to identify if and how these variations can be eliminated. Otherwise there is a risk that central heat storages are installed for a problem that can be solved locally at the variation source.

Acknowledgments

This work was financially supported by Fjärrsyn, the Swedish district heating research programme, and Öresundskraft. The support from the 20 district heating companies providing input data for the analysis was also highly appreciated.

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