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Cost considerations on storage tank versus heat exchanger for HTW preparation

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Cost considerations on Storage Tank versus Heat exchanger for htw preparation

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1 Introduction

The aim of this paper is to give an economical evaluation of the two typical principles of preparing htw, focusing on the system as a whole.

Due to high energy prices and competitiveness performance indicators like distributed heat ab DH plant versus charged heat to consumer, trend within DH net sizing in Denmark is going towards smaller branch media pipe dimension for single house areas.

Influence on the DH net pipe sizes is the hydraulic pipe load related to htw preparation and heating. Important factor for designing the distribution network is the influence of the simultaneity factor for htw and room heating.

This paper describes hydraulic and thermal load on DH net related to the principle of htw preparation and seasonal dependent heating load. The htw preparation is typically made by means of storage tank (ST) or a heat exchanger (HE) system.
htw load profile is based on Danish recommendations for sizing of htw systems. The investigation is based on calculations and laboratory measurements, e.g. tapping load profiles.

Also some general considerations on the specific benefits for the htw principle is made, and related to the economic evaluation.

2 The thermo hydraulic rating of the district heating unit

In Denmark the htw load profiles for one family houses are specified in DS439. The profile is specified for two different situations, a one family house with shower and no bath top and a one family house with shower and bath top. The load profiles are shown in fig. 1

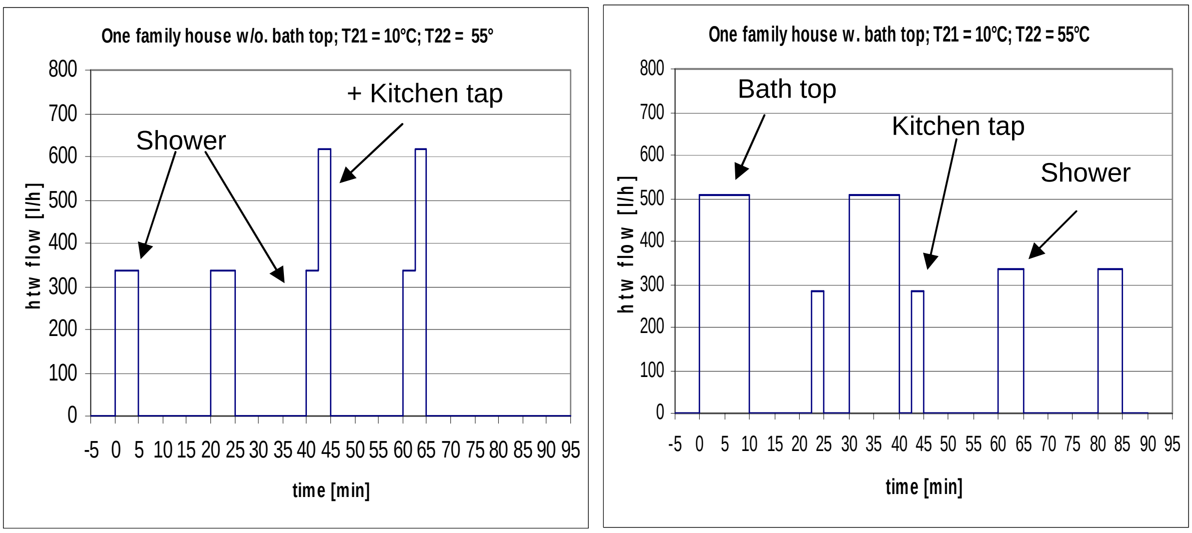

Figure 1: htw load profiles specified in Denmark, according to DS439.

The profiles in figure 1 are based on a tapping temperature of T_{22}=55°C and a cold water temperature T_{21} = 10°C. The specified power ratings are listed in table 1:

	w/o. bath top	w. bath top
Kitchen sink	14,7 kW	
Bath top		26,4 kW
Shower	17,6 kW	
Max. power	32,3 kW	26,4 kW

Table 1: htw power ratings according to DS 439.

The minimum tap temperature is 45°C, specified for the kitchen tap. The HE unit is dimensioned for 32,3 kW regardless if there is installed a bath top or not.

2.1 Storage tank unit

A typical storage tank unit used in e.g. Denmark is shown in fig. 2.

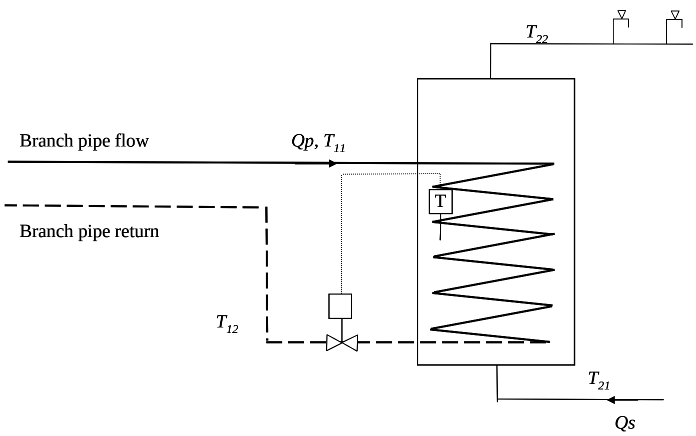

Figure 2: Storage tank unit, 110 litre volume, 17 meter of 3/8” coil installed

To determine the hydraulic load and return temperature on the primary side is not as straight forward to estimate as for the HE unit. Data sheets normally state flow and powers for constant flow conditions, which only indirect indicate operational performance. The applied control functions, e.g. the use of a flow limiter and thermostatic valve, has large influence on the result. A number of laboratory measurements are made on a ST unit, one example is shown in fig. 2. Since these results are dependent on the applied control principle, also a number of measurements are made under constant primary flow, to eliminate this effect.

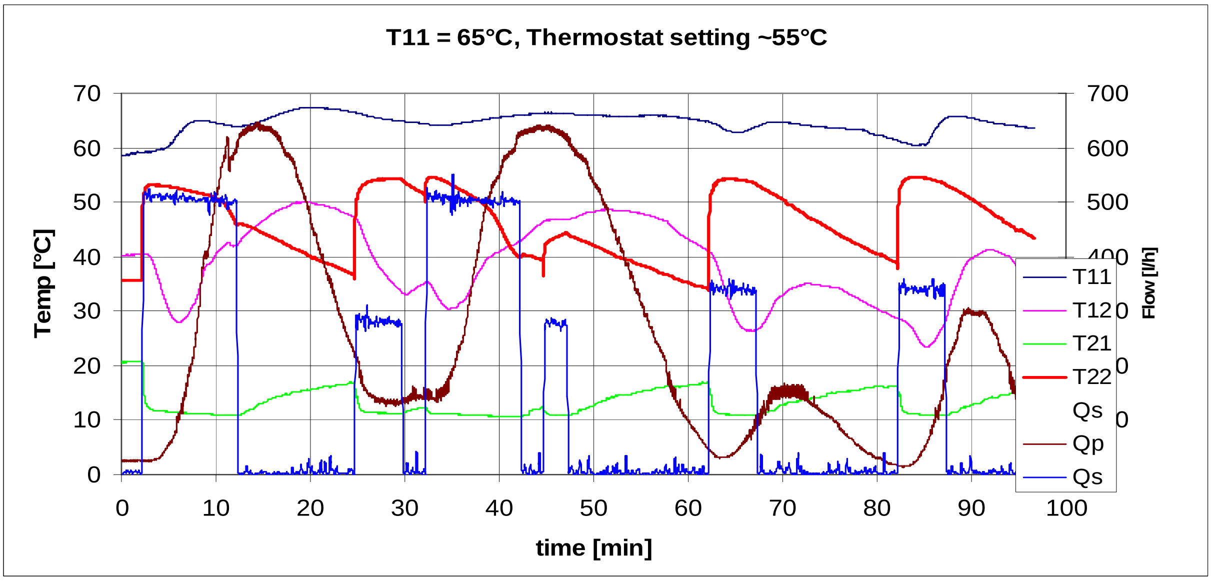

Figure 3: Example of tapping profile measurement applied on 110 litre ST unit

Initial condition for this test is a storage tank filled with approx. 55°C htw. As it can been seen in fig. 3, the primary flow is actually peaking with high flow values, and very direct related to the htw load profile. After the second bath top filling the htw temperature for the kitchen tap is just reaching 45°C (at time = 45 min). Primary differential pressure and valve kvs value influences the peaks and return temperatures. For the measurements a kvs value of 1.2 is used, and a differential pressure of approx. 30 kPa, which represents typical lower end of Danish supply conditions.

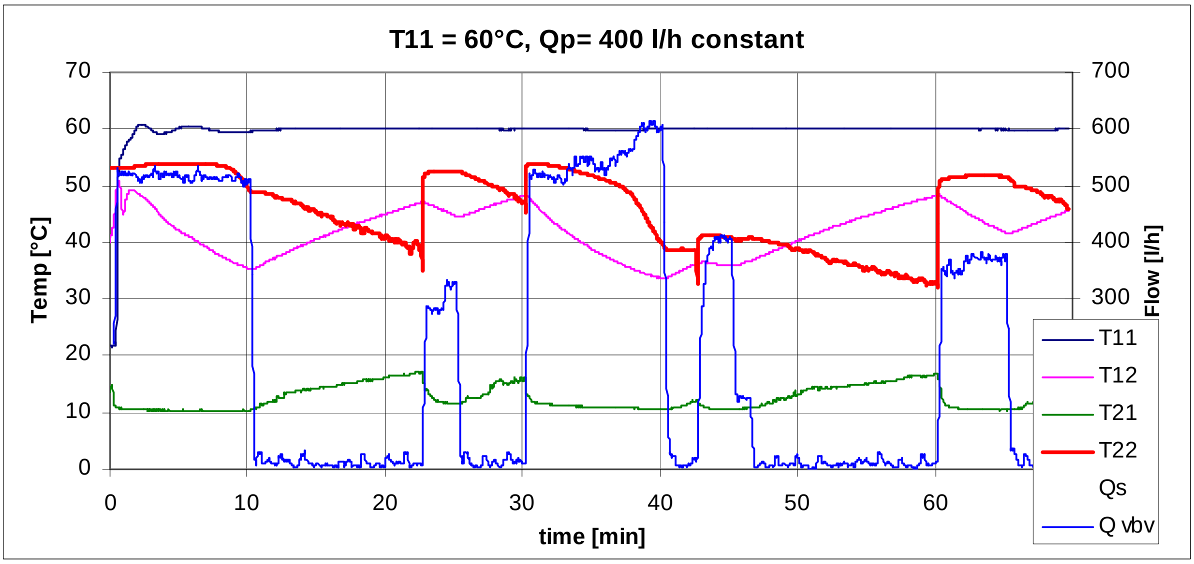

Figure 4: Example of tapping profile measurement applied on 110 litre ST unit, primary flow is constant

Due to the fact that the specifications are based on power, the htw tapping flow is increased when the htw temperature drops, see fig. 4 at time 35 min. Actually the tapping temperature at time = 45 min is below 45°C and therefore too low according to specifications.

Table 2 includes an overview on primary flow and return temperatures. To indicate a representative return temperature, the 1h maximum average return temperature and flow is used.

2.2 Heat exchanger unit

The HE unit performance is straight forward to describe. Fig. 5 includes the tapping program with a typical HE for htw for a one family house w/o. bath top.

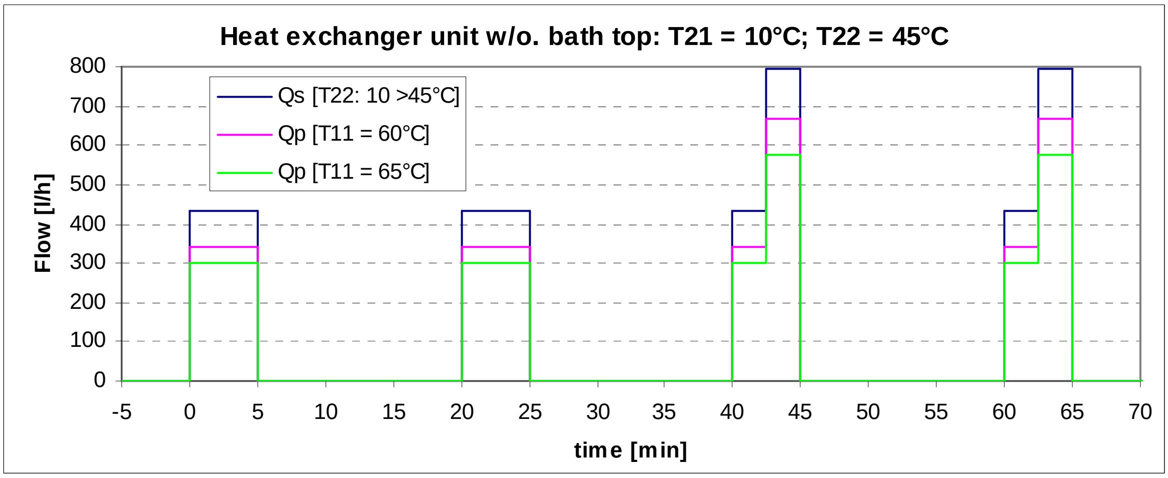

Figure 5: Heat exchanger hydraulic performance, heat exchanger type Danfoss XB06-1-34H

Compared to fig. 3 the maximum primary flow has approx. the same value, and this is also the typical experience from DH nets using HE compared to DH nets using ST.

2.3 Thermal hydraulic load comparison

Table 2 includes the htw thermal and hydraulic loads related to the unit types:

Unit type	T11 [°C]	T12* [°C]	T11-T12 [°C]	T22 [°C]	Qp* [l/h]	P [kW]
Storage tank 110 l w/o. bath top	60	42	18	55	280	5,8
Storage tank 110 l w/o. bath top	65	38	27	55	215	6,7
Storage tank 110 l w. bath top	60	45	15	55	490	8,5
Storage tank 110 l w. bath top	65	42	23	55	360	9,6
Heat exchanger	60	18	42	45	660	32,3
Heat exchanger	65	16	49	45	570	32,3

**) Max. of 1h average value*

Table 2: Thermal hydraulic load comparison

In table 2, the maximum one hour mean values are used for calculating the respective thermal and hydraulic load. To use the peak flow values from e.g. fig. 3 would be to pessimistic, since the control principle has highly influence on the peak values. On the other hand, to base the primary flow on the constant flow result, which clearly indicates the storage tank performance with no influence from the applied control equipment, would be to optimistic, since this does not represent a common control solution. An assumption to use the maximum 1h average values has been applied, and the calculated 1h flow values are slightly higher than the constant flow results.

3 Effects on design and operation of the distribution network

3.1 In short about the simultaneity factor

A simple method to calculate group design load of N consumers, Q(N) (kW), each having a design load of q_{max} (kW/cons) according to design standard, would be:

$$\text{(Design group load of N consumers)} = N * q_{max} = N * Q(1) \quad \text{(kW)}$$

However, the group load is found to be lower, as all of the N consumers do not tap water at the same time, and at least not use their maximum load at the same time. Further reduction is caused by over-design of q_{max}, etc. The simultaneity factor S is defined as

$$S(N) =: Q(N) / (N * Q(1)) \quad \text{(\% Design group load)}$$

where Q(N) is the maximum load from N consumers. Right evaluation of the simultaneity can save considerable amount of investment and operation costs of the pipe network, fig. 6.

In the literature, the S(100) can be found in surprisingly big range, even for similar types of units. Part of the reason may be different definitions or uncertainty about Q(1). On the other hand, Q(100) is a much more "stable" value than S(100). So instead of comparisons between simultaneity factors, comparison of average unit load, that is Q(N)/N (kW/consumer), is preferred in this paper.

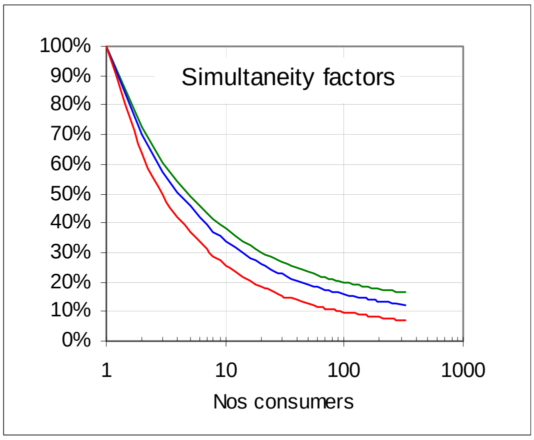

Figure 6: Example of simultaneity factors.

3.2 Pure HTW load on pipe network

A number of the previous works in Denmark regarding simultaneity of hot tap water dh load are included in the reference list. The most relevant results for this paper are presented as group loads (kW) and compared in fig. 7.

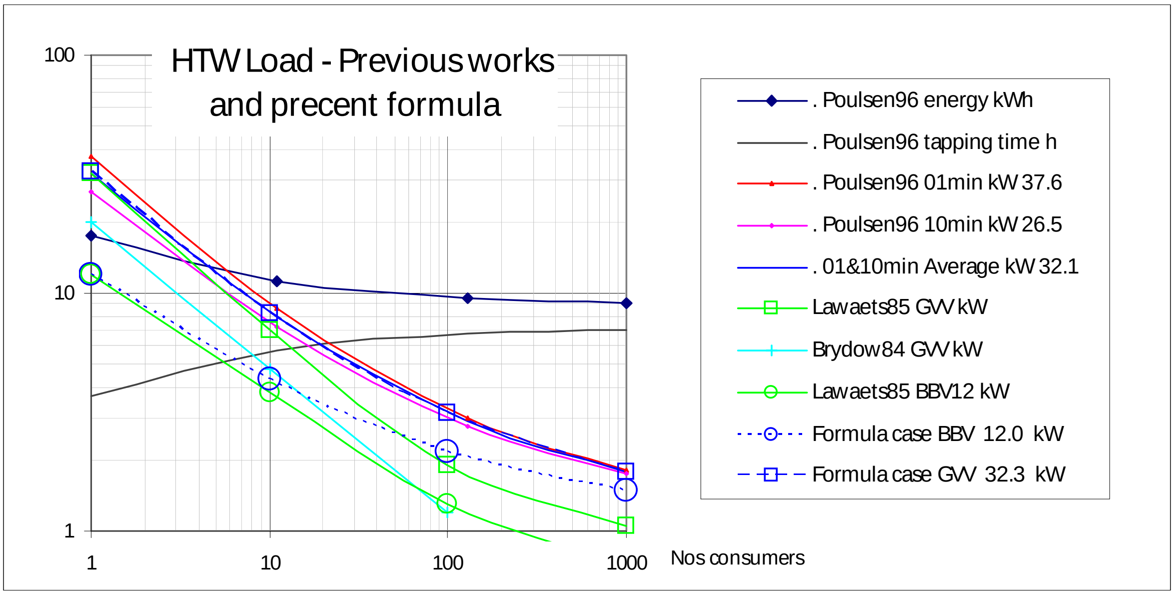

Figure 7: DH group load (kW) from pure htw consumption. Previous works in Denmark and formula used in this paper (GVV: HE heat exchanger, BBV: ST storage tank).

The loads found in (f.ex.) Poulsen 96 are based on principles in DN4708, but adjusted to Danish conditions. They show 1 minute maximum and 10 minute maximum load of 12 hours time interval. Curves of Brydow 84 and Lawaets 85 are based on measurements, and show lower loads. Lawaets works with a storage unit with max of 12 kW. The last two curves in the figure are two cases of the formula used for all unit types in this paper:

$$Q(N, q_{max}) = a * N + b(q_{max}) * N^{½} + c(q_{max}) \quad (kW)$$

where

$a = 1,19$
$c(q_{max}) = 13,1 * (q_{max} / 32,3)^{2,3}$
$b(q_{max}) = q_{max} – a - c$

The values / formulas of a, b, c is a result of evaluation of the curves of the previous works. The relative difference of load of storage tank and heat exchanger fits with Lawaets. The load Q(N) of heat exchanger fits with Danish design precondition of 32,3 kw, which is approximately the average of the one minute max and 10 minute max load of Poulsen96. The value 1,19 kW of the constant “a” represents the asymptotic or eventual average unit load regardless type of unit.

In the following, we will compare three cases from previous section, the dh load of respectively heat exchanger unit (HE) 32,3 kW (with or without bath top), storage tank unit (ST) with bath top 8,5 kW, and storage tank unit (ST) with shower 5,8 kW. In case of HE unit, the load Q(1) is the maximum momentum load, while in case of storage units, Q(1) is the maximum one hour average, (and not maximum, to take into account improvements in control of the storage tank). In all three cases, the forward temperature is 60°C. The comparison of heat load is found in the left side of fig. 8.

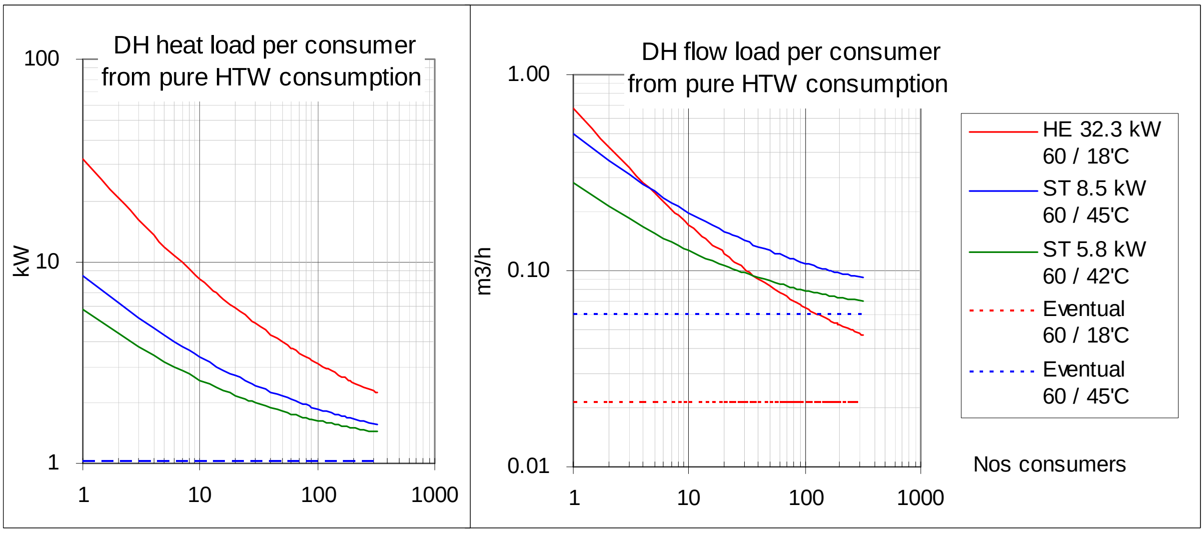

Figure 8: DH heat load per consumer and DH flow load per consumer of pure hot tap water consumption in the three cases with forward temperature 60°C, respectively HE unit 32,3 kW, ST unit w. bath top 8,5 kW, ST unit w/o. bath top, 5,8 kW.

It appears from the diagram, that the load of the HE unit is biggest, but decreases faster than the load of the ST units. The reason is of course that as the loads of the HE unit are “higher” on the kW scale, they also are “smaller” on the time scale, which gives smaller simultaneity. Both ST unit and HE unit decrease towards the same eventual value.

The flow load on the pipe network can be found in the right side of the figure. It depends on the heat load and the temperature drop at the consumers. The dh forward temperature is 60°C, and previous section showed return temperature of the heat exchanger unit of 18°C, and return temperatures of the tank units (1 hour average) of 42°C and 45°C. The dh flow load of the three units is found in the right side of the figure.

It appears from the diagram, that in case of few consumers, the flow load of the HE unit is higher than the flow load of the storage unit. In case of sufficient number of consumers, the flow load of the HE unit is lower, than in both cases of the storage unit.

3.3 Total load and sizing of pipe network

The room heat load $Q_r(N)$, also follows a simultaneity curve, though much less dramatic with eventual simultaneity factor of about 50-75% of $Q_r(1)$, depending on installations. Here we use S(eventual) = 62% and $Q_r(1)$ = 5 kW, that is design room heat load, and dh design temperatures of 70/35 °C (forward/return).

In principal the service pipe capacities are designed according to maximum htw load <u>or</u> maximum room heat load, at least in case of HE unit (the maximum of the two values). In case of single family houses, this usually means the maximum htw load. In case of storage tank, the design load may be slightly higher than the maximum of the room heat and htw part, the reason being that the ST unit occupies the service pipe in a longer period than than the HE unit.

Other pipes in the network are basically designed to have capacity for both maximum room heat and maximum hot tap water demand to some extend. According to a traditional convention, only part of the htw load is added to the room heat load, as maximum htw load and maximum room heat load occur rarely. However to much reduction in the htw addition load becomes a dangerous method of pipe sizing in case of low room heat loads. Here, the htw add percentage in case of all unit types is found according to

(htw add %) = (32,2- $Q_r(1)$) / 32,3)
(Total load) = (Room heat load) + (htw add) (kW)
(htw add) = (htw add %) * Q(N)

Here, (htw add %) = 85 % as $Q_r(1)$ = 5 kW.

The resulting total heat load per consumer on the pipe network can be found in fig. 9.

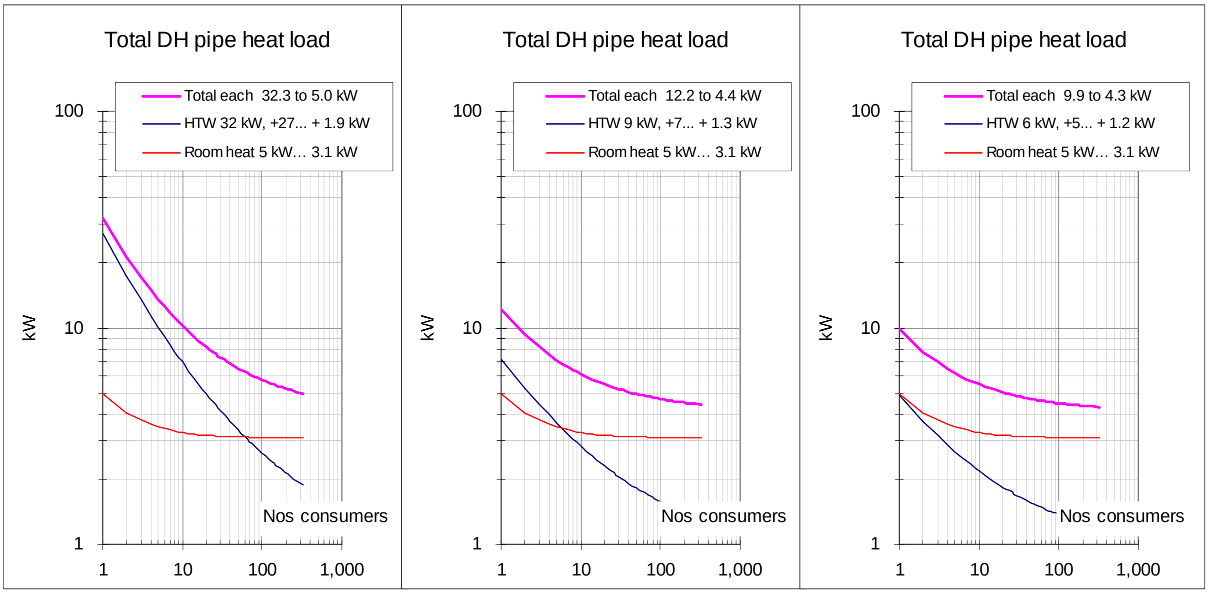

Figure 9: DH heat load per consumer of room heating and hot tap water in the three cases with forward temperature 60°C, respectively HE unit, ST unit with bath top, ST unit with shower.

The figure shows that in case of 1-10, maybe 20 cosumers, the heat load of the ST unit is considerable lower than the heat load of the HE unit.

However, the pipes are sized according to flow load, not heat load, and the flow load of the pipe network depends on the previously mentioned values of DH temperatures. The flow load can be found in fig. 10.

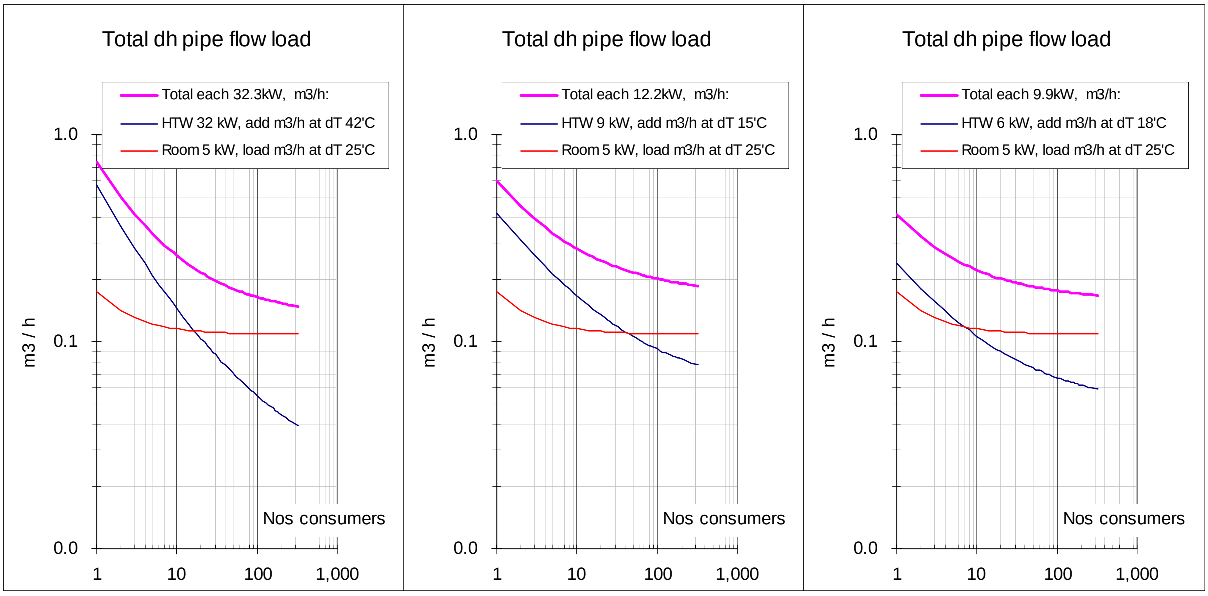

Figure 10: DH flow load per consumer of room heating and hot tap water in the three cases with forward temperature 60°C, respectively HE unit, ST unit with bath top, ST unit with shower.

To simplify the presentation, the figure shows only one case, which we have choosed to be winter design load with forward temperatures of 60°C. But in fact the pipe design takes – and has to take - into account winter-, and summer situation separately, as the summer condition is critical for the pipes serving one to few consumers, while the winter condition is critical for the rest of the network.

The figure shows that the flow load of the HE unit is higher than the flow load of the ST unit in case of pipes serving 1- 3 consumers, while the flow load of the HE unit is lower in case of pipes serving more than 30 consumers. In case of 4-30 consumers ST unit has higher load than HE unit in case of bath top, but lower in case of shower.

Now we have found the design flow load for every pipe section in the network. This information we have put into a pipe network sizing software, where all pipes and pump stations are automatically sized. The pipes are sized according to the optimal design pressure gradient (bar/km), which runs from about 1 bar/km for medium sized pipes, to about 10 bar/km in case of service pipe for typical price conditions in Denmark /Kristjansson 1994/.

The next task is to compare the total distribution costs in case of the three pipe network designs, according to the three cases mentioned above.

3.4 Cost of distribution system in three cases

The cost of pipe network is calculated as the sum of investment in pumps and pipes as well as operation costs including electricity consumption of pumps and heat losses from pipes.

For calculating investments, we use a model developed in Kristjansson et al. (2004). The pipe investments consist of the production costs of the pipe itself, the component costs (branch tees etc.) which depend on the network structure, and the cost of pipe works and civil works. The model is multivariable regressed with price structures from pipe producers and entrepreneurs, and verified with completed projects. The model includes data about typical average pipe network geometry.

Operation costs including heat losses and electricity consumption are present valued with a time horizon of 20 years, and interest of 5%. The prise of heat loss is set according to typical values for Danish conditions. The results of total cost comparison is the following table 3:

Total distribution cost in 20 years	Relative	EUR / year / consumer	EUR / consumer	+EUR / consumer
Heat exchanger 32,3 kW (shower and bath top)	100%	191	3830	0
Storage tank 8,5 kW (shower and bath top)	102%	196	3920	+90
Storage tank 5,8 kW (shower only)	98%	188	3770	-60

Table 3: Total distribution costs in 20 years

The results in the table show, that in case of one family house with shower, the storage tank results in a slightly cheaper distribution cost than the heat exchanger unit, savings about EUR 60. In case of on family house with bath top, the storage unit demands EUR 90 more expensive distribution, than the HE unit. In both cases the difference between the heat exchanger unit and the storage tank unit with respect to distribution cost is only 2%, and this number is to low for concluding that one of the unit types results in bigger distribution costs than the other.

To summarize, the HE unit demands bigger pipe sizes in pipes serving few consumers due to higher heat load, but it demands smaller pipe sizes in case of pipes serving a fair number of consumers, due to better temperature drop. The heat exchanger unit and storage tank unit result in approximately the same total distribution costs.

4 Qualitative Considerations

The general discussion on the advantages / disadvantages related to the selected unit type is typically covering the following issues:

4.1 Benefits of storage tank:

Lower peak load if adequate control equipment is installed, e.g. thermostat and flow limiter.
htw availability is independent of short interruptions in DH supply.
htw flow independent tapping temperature, meaning no peak temperatures at flow change.
Robust against scaling. A to high htw temperature setting applied in hard water areas might result in scaling for HE unit.

4.2 Benefits of heat exchanger:

Reduced risk of legionella bacteria.
Space savings and more up to date technology and appearance. Typical square meter price for one family house is 1.500 EUR/m^2.
Low return temperature during tapping.
Unlimited tapping time, improving consumer comfort.
Heat loss from HE unit can be close to zero, if the heat exchanger is bypassed on primary side at idle.
Heat exchanger can be operated at e.g. 45°C htw temperature, which reduces secondary distribution heat loss compared to typically higher htw temperature for storage tank, due to capacity considerations.
The installation requires only one installer due to low weight of the unit, resulting in low installation costs. The ST requires typically two installers.

4.3 General:

The storage tank unit and heat exchanger unit has similar purchase price for comparable functionality.

5 Conclusion

Based on a DH network supplying 300 one family house consumers, there are basically no net distribution cost differences over a 20 year period for the storage tank unit versus the HE unit. Taking other factors like building area cost related to unit space consumption into consideration moves the economic favour towards the heat exchanger unit. Also the possible lower operational heat loss and the reduced installation costs for the heat exchanger unit support this. Looking at the listed qualitative considerations the benefit of the heat exchanger unit is more end customer oriented, while the benefit of the storage tank unit is more DH utility oriented. Anyhow, the lower return temperature from the heat exchanger unit is a benefit for the DH utility.

During the years the DH net consequences for storage tanks versus heat exchanger units have been discussed in Denmark. The recommendations from DH utility side is in majority pointing towards storage tank units, which can not be supported based on the results from this paper.

6 References

Code of Practise for domestic water supply installations.
DS 439, 3. udgave

Kristjansson H., Bruus F., Bøhm B. et al. 2004.
Fjernvarmeforsyning af lavenergiområder (District heating supply of low heat density areas). In Danish. 106p. Carl Bro as and Technical University of Denmark. ISBN 87-7475-315-0.

Paulsen, Otto, april 1996
Dimensionering af vandvarmere – et nyt dimensioneringsgrundlag baseret på dynamisk simulering, Dansk Teknologisk Institut, ISBN 87-7756-442-1

Lawaetz, Henrik 1988
Dimensioneringsforudsætninger for fjernvarmeanlæg til boliger, Dansk Teknologisk Institut, ISBN 87-7511-895-5

Lawaetz, Henrik 1988
Vandvarmere til fjernvarme, Dansk Teknologisk Institut, ISBN 87-7511-011-0

Lawaetz, Henrik maj 1985
Varmtvandsforbrug i boliger – målinger af vand- og energiforbrugets størrelse og fordeling, Dansk Teknologisk Institut, ISBN 87-7511-544-1

Lawaetz, Henrik 1985
Samtidighedsforhold ved vandopvarmning i boliger, Dansk Teknologisk Institut, ISBN 87-7511-533-6

Brydow, P.M. 1984
Forbrugsbelastning og samtidighedsforhold i fjernvarmenettet. Energiministeriets energiforskningsprogram, FJV 22.

Lawaetz, Henrik 1984
Brugsvandsopvarmning. Kort gennemgang af DIN4708, ISBN 87-7511-449-6

DIN 4708, part 1,2,3, y1979