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Delrapport 3

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Miscellaneous investigations

May 2011

AFFALDVARME ÅRHUS

Høje Taastrup Fjernvarme A.m.b.A

Foreword

This report is the 3rd part out of three in the project "CO_2-reductions in low-energy buildings and communities by implementation of low-temperature district heating systems. Demonstration cases in EnergyFlexHouse and Boligforeningen Ringgården". The project is subsidised by the Danish Energy Agency through the energy research programme EUDP 2008-II and is carried out by the following project consortium with Energitjenesten as Project Manager and COWI A/S and DTU-BYG as Task Managers on Subtask 3:

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This report is a collection of results for the project's subtask 3: Miscellaneous investigations. The miscellaneous investigations refer to analyses regarding optimisation and implementation of low-temperature district heating and an assessment of CO_2-reduction potentials.

The project consortium would like to offer specials thanks to BSc student Mette Veith Schroeder, BYG-DTU, who has contributed with detailed analyses regarding optimisation and implementation of low-temperature district heating to existing buildings. Also the project consortium would like to thank Tomas Mikeska, M.Sc. for carrying out Bsim simulations for investigation of possible reduction of peak loads for space heating.

The report is written in English because different nationalities among the project partners have delivered input to the report.

May 2011, DTU-BYG, Marek Brand & COWI A/S, Peter Kaarup Olsen, Task Managers

Summary

The report focuses on possibilities of how to further decrease CO_2 emissions by implementation of low-temperature district heating (LTDH) in areas with new low-energy buildings as well as in areas with existing buildings.

In the first chapter, three different sites where LTDH is considered are reported. The first site is in Solbjerg near Aarhus, where 104 low-energy single-family houses are planned to be built. Calculations for a LTDH network (60/30°C) have been made in the program TERMIS. The results show that depending on the houses being built as low-energy class 1 or 2, a cost saving potential of 6-13% can be achieved compared to traditional district heating (DH). The CO_2-reduction potential is 4.4-7.5 tonnes per year. The results also show that there is only a small difference in costs (construction costs and 20 years of operation) between the different types of in-house substation units. Please note that today most standard house companies offer only low-energy houses with heat pumps, although LTDH is considered to be a fully competitive heat supply solution. Through dialogue and information, AffaldVarme Aarhus is trying to change that.

The second reported site is an area with single-family houses built in the 1970s in Skjoldhøjparken in Tilst near Aarhus. Eight single-family houses have been investigated. Some houses have an undersized radiator system and use a wood stove as a supplementary heating source. Refurbishment can reduce the heat demand and make the houses more suitable for LTDH, but even with subsidy it is difficult to motivate the building owners to make energy saving initiatives like improvements of the building envelope and heating installations. Analyses show that if the DH supply temperature is lowered gradually from 80°C to 60°C, depending on the outdoor temperature, the heat loss in the existing pipe network for the eight houses can be reduced by 20%. An even larger potential can be achieved with replacement of the existing pipe system.

The third site is neighbourhood in Sønderby in Høje Taastrup with 75 single-family houses from the 1990s. The existing DH network is poor and has a heat loss of more than 40%. With LTDH it will be possible to reduce the network heat loss to 15% or lower. The CO_2-emission could be reduced by about 66 tonnes per year. A new EUDP project will ensure that the existing DH network will be replaced, and LTDH will be implemented.

In the second chapter we describe existing district heating systems in Aarhus and Høje Taastrup. The average DH temperature is currently 80-77/47-42°C, so there is a potential for LTDH. The network heat loss in the DH systems is 15-16%. Residence buildings account for the largest part of the heat consumption, but also a large number of industry and commercial buildings are supplied with DH. Both AffaldVarme Aarhus and Høje Taastrup Fjernvarme are continually renewing the existing DH system, and newly built housing areas and areas converted from natural gas are being connected. Both DH companies are working on gradually lowering the DH temperature, and there are plans of having a CO_2-neutral heat supply within 15-20 years.

Lowering the DH temperature from 80/40°C to 55/30°C can reduce existing network heat loss by about 35%. With an optimal pipe system, the saving potential can be increased to 50-75%. The CO_2-reduction potential for Høje Taastrup Fjernvarme is between 7-10%, and for

AffaldVarme Aarhus, the reduction potential it is calculated to be 11-16%. In total for Denmark, the reduction potential is assessed to be up to about 1,000,000 tonnes CO_2 per year, corresponding to about 1/5 of the total yearly emission for DH.

The third chapter reports investigations on the possibility of supplying existing typical buildings built in the 1970s with LTDH with a supply temperature around 50°C. It is shown that basic renovation measures such as a change of the windows allow decreasing the maximum supply temperature needed for space heating (SH) system to 50°C for most of the heating season, but in case of outdoor temperatures below 0°C, the supply temperature should be increased. It is, however, not seen as a problem, because increasing the supply temperatures for cold periods is widely used in the traditional DH concept. The level of supply temperature needed for operation of SH systems in existing buildings can be further reduced by exchange of existing radiators by low-temperature radiators (larger surface) or by further renovation measures on the building envelope.

A transition of all existing buildings to LTDH is also connected with change of DH in-house substations. DH in-house substations equipped with DHW storage tank should be changed if the DH supply temperature is reduced below 60°C at any time during a year (because of Legionella risk), and GVV units should be changed if the supply temperature drops below 55°C (not enough efficiency to supply design temperature of domestic hot water). It is suggested to replace all traditional substations by new types specially designed for LTDH. Moreover, if the domestic hot water (DHW) system is operated with DHW temperature below 55°C, maximal volume of water in all DHW feeding pipes and circulation pipes is limited to 3 litres.

In the next chapter we show examples of typical heat demands and peak power for DHW heating and SH in low-energy single-family houses as well as in existing typical single-family houses from the 1970's. The reported peak power for individual houses is later used as a base for evaluation of reduction of peak power in the district heating network (DHN). The hypothesis is that if peak power for individual buildings can be reduced, pipes with smaller diameter are required in the DHN. Thereby the network heat loss can be reduced, and CO_2-emissions will be minimized.

The possibilities in reduction of peak power are studied for SH systems and for DHW heating. The reduction of peak power for SH systems equipped with properly designed radiators has low potential because possible reduction is very limited and can easily result in reduction of thermal comfort for users. In case of floor heating system, reduction of peak power can be up to 40% if the heating system is operated with continuous supply of heating water instead of on/off control, which can cause high peak power demand. Moreover, by continuous supply of heating water to the floor heating system, better thermal comfort for users and better cooling of heating water returning back to DH are reached.

Reduction of peak power for SH system is very important because the simultaneity factor of SH will never be lower than 62% of the total heat demand in all buildings and thus for pipes supplying higher number of customers, it defines the needed flow capacity of DHN. For dimensioning of branch pipes (supplying only one customer), the importance of reduction of peak power for SH depends on the type of DH substation used. In case of GVV (IHEU - Instantaneous Heat Exchanger Unit) unit - a unit without buffer tank - there is no influence on sizing of the branch pipe, because the branch pipe should be designed for the peak power of 32.3 kW for DHW heating. The situation is different in case of a substation with buffer tank – FVB (DHSU - District Heating Storage Unit), where the level of possible downsizing of the branch pipe depends on the size of the buffer tank and the maximal charging flow rate from DHN.

Reduction of peak power/load for DHW is mainly of importance for the parts of DHN supplying a lower number of consumers. In the previous EFP 2007 project [2], a concept and prototype of a FVB unit were developed in order to be able to reduce the peak power for DHW heating. In this report is looked into optimization of the FVB unit, where the needed DHW priority and the level of comfort for customers should be kept. The optimization of FVB is based on finding the optimal balance between a size of the buffer tank and maximal charging flow rate from DHN, while using a branch pipe with the smallest diameter available (Aluflex 14/14/110). The main advantage of the optimized concept is the reduced size of substation (size of buffer tank is reduced from 120 litres to 20-60 litres depending on "stand-by" temperature and designed pressure drop in DHN) and better utilization of available flow capacity and pressure gradient in the DHN, allowing reduction of pipe diametre and thus heat loss from the DHN.

For single-family houses using an optimized FVB with 20-litre buffer tank, the peak power for dimensioning a branch pipe can be reduced from 32.3 kW to 12.5 kW, if maximum charging flow rate is 5.5 litre/min. (corresponding to branch pipe Aluflex 14/14/110 with design pressure drop 2000 Pa/m). For networks with lower available pressure gradient, maximal charging flow/power can be further reduced. This will result in increased size of the buffer tank and the whole substation, in increased price of substation and higher heat loss from the substation. Moreover, for FVB with reduced charging flow rates, a priority of DHW heating cannot be used. And for branch pipe dimensioning should be used peak power for space heating added to the charging power for DHW.

The developed concept of FVB with reduced size of buffer tank shows high potential for reduction of dimensions and heat losses from DHN, but optimal balance between size of buffer tank and pressure drop in the DHN should be further investigated.

Furthermore, two solutions are suggested for optimal operation of the proposed in-house DH substation; "comfort bathroom" which is an alternative to traditional by-pass using circulated water for all-year-around heating of bathroom floor and "on demand by-pass", allowing cooling down of branch pipe without any influence on comfort for DHW tapping. The simple calculations show that all-year-around supply of floor heating has no critical influence on overheating in low-energy houses, and users get an pleasant sensation of warm floor at a very low cost. The concept of "comfort bathroom" is beneficial also for the whole DHN because DH water is kept in circulation, meaning full-way instead of traditional by-pass, which should be used in some parts of the DHN anyway. Moreover, the concept can be used for traditional GVV units instead of traditional by-pass as well.

The last chapter encompasses some other issues for LTDH. Heat loss in pre-insulated pipes, LTDH network with recirculation and a direct heat exchanger unit for single-family houses have been investigated.

Resumé

Rapporten fokuserer på mulighederne for, at reducere CO_2-udledningen med etablering af lavtemperatur fjernvarme (LTDH) i områder med nye lavenergi-bygninger samt i områder med eksisterende bygninger.

I det første kapitel er der undersøgt tre forskellige steder, hvor der er mulighed for at etablere LTDH. Det første sted er i Solbjerg ved Aarhus, hvor 104 lavenergi-parcelhuse er planlagt opført. Beregninger for et LTDH-net (60/30°C) er blevet foretaget i programmet TERMIS. Resultaterne viser, at økonomisk er besparelsespotentialet på 6-13% afhængigt af, om husene er bygget som lavenergiklasse 1 eller 2. I sammenligning med traditionel fjernvarme (DH) er CO_2-reduktionspotentialet beregnet til 4,4-7,5 tons pr. år. Resultaterne viser også, at der kun er en lille forskel i omkostningerne (byggeomkostningerne og 20 års drift) imellem de forskellige typer af fjernvarmeunits i husene. Det er værd at lægge mærke til, at de fleste typehusfirmaer i dag kun tilbyder lavenergihuse med varmepumper, selvom LTDH kan anses for at være en fuldt konkurrencedygtig varmeforsyning. AffaldVarme Aarhus forsøger med dialog og information at få byggebranchen til at ændre dette syn på muligheden for fjernvarme.

Det andet sted, der er set på, er Skjoldhøjparken i Tilst ved Aarhus, som består af parcelhuse bygget i 70'erne. Otte enfamiliehuse er blevet undersøgt. I forhold til at få varme nok ved lavere fjernvarmetemperaturer viser undersøgelsen flere barrierer. Nogle huse har et underdimensioneret radiatorsystem og bruger typisk brændeovn som supplerende varmekilde på de koldeste dage. En bygningsrenovering kan reducere varmebehovet og gøre husene mere egnet til LTDH, men selv med tilskud er det svært at motivere bygherrer til at gå i gang med energibesparelser, der typisk kunne være forbedringer af klimaskærmen og varmeanlæg. Analyser viser, at hvis fremløbstemperaturen på fjernvarmen sænkes gradvist fra 80°C til 60°C afhængig af udetemperaturen, kan varmetabet i det eksisterende fjernvarmenet for de otte huse reduceres med 20%. Et endnu større potentiale kan opnås ved udskiftning af det eksisterende fjernvarmenet med nye optimale rør.

Den tredje sted er boligkvarteret Sønderby i Høje Taastrup med 75 parcelhuse fra 90'erne. Det eksisterende fjernvarmenet er i dårlig stand og har et varmetab på over 40%. Med LTDH vil det være muligt at reducere varmetabet til 15% eller lavere. CO_2-udledningen kan reduceres med omkring 66 tons pr år. I et nyt EUDP-projekt vil det eksisterende fjernvarmenet blive udskiftet og drevet efter LTDH-principperne.

I det andet kapitel beskrives de eksisterende fjernvarmesystemer i Aarhus og Høje Taastrup. De gennemsnitlige fjernvarmetemperaturer er i øjeblikket 80-77/47-42°C, så der er et potentiale for LTDH. Varmetab i fjernvarmenettene er 15-16%. Boligbebyggelser tegner sig for den største del af varmeforbruget, men også et stort antal af industri- og erhvervsbygninger forsynes. Både AffaldVarme Aarhus og Høje Taastrup Fjernvarme renoverer løbende de eksisterende fjernvarmenet og udbygger i nybyggede boligområder, og der er områder med individuel opvarmning med naturgas, som nu bliver konverteret til fjernvarme. Begge selskaber arbejder på gradvist at sænke fjernvarmetemperaturerne, og der er desuden planer om at gennemføre CO_2-neutral varmeforsyning inden for 15-20 år.

At sænke fjernvarmetemperaturerne fra 80/40°C til 55/30°C kan reducere varmetabet med ca. 35% i fjernvarmenettene. Derudover kan optimalt dimensionerede rørsystemer øge den potentielle besparelse til 50-75%. CO_2-reduktionspotentialet for Høje Taastrup Fjernvarme er mellem 7-10%, og for AffaldVarme Aarhus er det beregnet til 11-16%. I alt for Danmark vurderes reduktionspotentialet at være op til ca. 1.000.000 tons CO_2 om året, svarende til ca. 1/5 af den samlede årlige emission fra fjernvarmen.

Det tredje kapitel undersøger mulighederne for at forsyne eksisterende bygninger opført i 70'erne med fjernvarme ved fremløbstemperaturer omkring 50°C. Det vises, at grundlæggende forbedringer som for eksempel ved renovering af vinduerne, gør det muligt at nedsætte den maksimale fremløbstemperatur til 50°C. Denne temperatur er nødvendig for rumopvarmning i det meste af fyringssæsonen, men ved udendørstemperaturer under 0°C bør temperaturen øges. Det ses imidlertid ikke som et problem, da øget forsynings-temperatur i kolde perioder er udbredt i traditionel fjernvarme. Temperaturniveauerne til rumvarme kan yderligere reduceres ved udskiftning af eksisterende radiatorer med lavtemperatur-radiatorer (større overflade) eller ved yderligere energirenovering af klimaskærmen.

Skift fra traditionel fjernvarme til LTDH er i eksisterende bygninger forbundet med ændring af brugerinstallationer. Fjernvarmeinstallationer med brugsvandsbeholdere bør ændres, hvis fremløbstemperaturen kommer under 60°C i løbet af året (på grund af Legionella-risiko). Og units med gennemstrømningsvandvarmere (GVV) skal ændres, hvis fremløbstemperaturen falder til under 55°C, fordi det traditionelle design ikke er effektivt nok til produktion af varmt vand ved den lavere fjernvarmetemperatur. Derfor vil det være nødvendigt at skifte hoveddelen af de traditionelle fjernvarmeunits med nye typer, der er specielt designet til LTDH. Desuden bør fordelingssystemet til varmt brugsvand ikke indeholde over 3 liter vand, hvis brugsvandstemperatur er under 55°C.

I det næste kapitel vises eksempler på typiske krav til spidseffekt for brugsvand og rumvarme i lavenergienfamiliehuse samt i eksisterende typiske parcelhuse fra 70'erne. Den målte spidsbelastning for de enkelte huse er brugt som basis for evaluering af nedsættelse af spidseffekt i fjernvarmenettet. Hypotesen er, at hvis spidseffekt for de enkelte bygninger kan reduceres, kan man også reducere diametrene i fjernvarmerørene. Dermed kan varmetab og CO_2-emissioner minimeres.

Mulighederne for reduktion af spidseffekt er undersøgt for rumvarme og brugsvandsopvarmning. I bygninger med gulvvarme kan spidseffekten reduceres op til 40%, hvis varmesystemet drives med løbende cirkulation i stedet for on/off styring, som kan forårsage højt spidseffektbehov. Desuden kan løbende cirkulation i gulvvarmesystemet give bedre termisk komfort for brugerne, og det kan sikre en bedre afkøling i forhold til fjernvarmen. Det bør undersøges, om udskiftning af radiatorer til lavtemperatur-radiatorer kan give gener i forhold til termisk komfort.

Reduktion af spidsbelastning i rumvarmesystemet er vigtig, idet samtidighedsfaktoren for rumvarme ikke kommer under 62% af summen af det samlede varmebehov for alle bygninger, og den dermed definerer flowet i fjernvarmeledninger, der forsyner mange forbrugere. For stikledninger afhænger vigtigheden af spidseffektreduktionen af fjernvarmeunittypen. I tilfælde med gennemstrømningsvandvarmere på brugsvandet har rumvarmen ingen indflydelse på dimensionering af stikledningen, da den dimensioneres til den maksimale effekt på 32,3 kW ved brugsvandsopvarmning. Situationen er anderledes i tilfælde af en fjernvarmeunit med buffertank - FVB (DHSU - District Heating Storage Unit), hvor mulighederne for at minimere fordelingsledningerne afhænger af størrelsen af buffertanke og maksimalt flow i fjernvarmenettet.

Reduktion af spidseffekt til varmt brugsvand har primært betydning for de yderste dele af fjernvarmenettet, hvor et mindre antal forbrugere forsynes. I det tidligere EFP 2007 projekt [2] blev der udviklet koncept og prototype for en FBV-unit med henblik på nedbringelse af den maksimale spidseffekt. I denne rapport er der set nærmere på optimering FVB-unitten, hvor den nødvendige brugsvandsopvarmning og et rimeligt komfortniveau for forbrugerne forsat skal sikres. Optimeringen af FVB-unitten er baseret på at finde den optimale balance mellem en størrelse buffertank og maksimal opladning flow fra fjernvarmenettet ved den mindste rørdimension, der findes (AluFlex 14/14/110). Den største fordel ved optimeringen er den reducerede størrelse af buffertanken fra 120 liter til 20-60 liter afhængig "stand-by"-temperatur og beregnet trykfald i fjernvarmenettet.

En optimal udnyttelse af den disponible flowkapacitet og trykgradient i fjernvarmenettet tillader nedsættelse af rørdiameter og dermed varmetabet fra fjernvarmenettet. For et parcelhus med en optimeret FVB med 20-liter buffertank betyder det, at den maksimale effekt ved dimensionering af en stikledning kan reduceres fra 32,3 kW til 12,5 kW. Det er under forudsætning af, at bufferbeholderen maksimalt lades med 5,5 liter/min. (stikledning AluFlex 14/14/110 med design trykfald 2000 Pa/m). For fjernvarmenet med en lavere trykgradient til rådighed kan det maksimale flow begrænses yderligere. Det vil resultere i en større bufferbeholder (FVB), og det øger prisen på unitten og varmetab fra installationen. Desuden vil et for ringe flow i fjernvarmenettet betyde, at stikledningen skal dimensioneres efter effektbehov til rumopvarmning plus effekt til opladning af bufferbeholderen.

Det udviklede FVB-koncept med reduceret størrelse buffertank viser et stort potentiale for reduktion af rørdimensioner og varmetab i fjernvarmenettet, men optimal balance mellem størrelsen af buffertank og trykfald i fjernvarmenettet bør undersøges nærmere.

Desuden er der foreslået to løsninger til optimal drift af de skitserede units. "Komfort badeværelse" er en gulvvarmestyring, der er et alternativ til det traditionelle by-pass, hvor der cirkuleres vand hele året rundt til opvarmning af badeværelset. Den er også et alternativ til "on demand by-pass"-løsningen, der afkøler stikledningen uden nogen indflydelse på komfort ved forbrug af brugsvand. Den enkle beregning viser, at helårscirkulation af gulvvarme ingen afgørende indflydelse har på overophedning i lavenergihuse, og brugerne får en behagelig følelse af varmt gulv til en lav pris. Konceptet "Komfort badeværelse" er også til gavn for fjernvarmesystemet, fordi fjernvarmevand holdes i cirkulation og kan benyttes i stedet for de traditionelle by-pass, som normalt er installeret i fjernvarmenettets mange yderpunkter. Desuden kan konceptet bruges til traditionelle installationer med gennemstrømningsvandvarmere i stedet for by-pass i nettet.

Table of content

Abbreviations

AVA	AffaldVarme Aarhus (Aarhus District Heating)
BOPU	Booster pump
BP	Branch pipe (service pipe connecting street pipe with district heating substation in a house)
CB	Comfort bathroom
CC	Cold charging
DH	District heating
DHN	District heating network
DHSU / FVB	District heating storage unit / fjernvarmebeholderunit
DHW	Domestic hot water
DHWC	Domestic hot water circulation
DHWSU /VVB	Domestic hot water storage unit / varmtvandsbeholder unit
DKK	Danish kroner
ECL	Name of controller from Danfoss
EFP	Energiforskningsprogram (former Energy Research Programme by the Danish Energy Agency)
EUDP	Energiteknologisk Udviklings- og Demonstrationsprogram (Energy Research and Demonstration programme by the Danish Energy Agency)
HEX	Heat exchanger
HTF	Høje Taastrup Fjernvarme (Høje Taastrup District Heating)
IHEU / GVV	Instantaneous heat exchanger unit / gennemstrømningsvandvarmer unit
LEC	Low-energy class
LEH	Low-energy house
LTDH	Low-temperature district heating
PTC2+P	Proportional-thermostatic controller from Danfoss
PEX	Plastic pipe (branch pipe)
SH	Space heating
SUB	District heating substation

1 Introduction

1.1 Background

The background for the project is described in detail in the other project report [1] about the demonstration in Lystrup. District heating is seen as a very important technology in combination with renewable energy to bring down the CO_2-emission related to the heat demand of buildings. The previous EFP project [2] and the demonstration in Lystrup [1] have defined and investigated the design of low-temperature district heating (LTDH) for low-energy houses. This was just the first step in the process for introducing LTDH and the concept should be further optimised for higher efficiency, lower cost and higher comfort for customers.

Denmark is aiming to be CO_2-neutral and thus it is important to reduce energy demand as much as possible. Major part of the building stock consist from existing buildings which represents the main part of heat demand and thus it is highly relevant to investigate and introduce the LTDH concept also for existing buildings. Nevertheless it is connected to some challenges, because space heating systems in existing buildings were originally designed for high-temperature operation.

Further it is relevant to assess the CO_2-potential by introducing LTDH in selected district heating systems and dwelling areas as well as for the whole of Denmark.

1.2 Objective

The objective is to assess the potential for CO_2-reductions and energy savings in new as well as in existing communities for LTDH.

Further the objective is to investigate implementation of LTDH in existing buildings and to investigate optimization of the LTDH design in general.

1.3 Description of the task

This project task has been divided into a row of subtasks, which are described below:

1. **Examples of sites in Aarhus and Høje Taastrup for low-temperature district heating**
   Description and calculations for 3 different sites where LTDH is considered to be introduced. Calculation of the CO_2-reduction potential.

2. **Description of DH systems and potentials for energy savings and CO2-reductions**
   Description of existing district heating systems and future plans in Aarhus and Høje Taastrup. Estimation of the energy savings and CO_2-reduction potential for implementation of LTDH in Aarhus, Høje Taastrup and in all of Denmark's existing district heating systems.

3. **Refurbishment of existing buildings and implementation of low-temperature district heating**
   Investigation of possibilities for LTDH in connection with refurbishment of buildings and district heating networks.

4. **Studied optimization and applications of low-temperature district heating potential**
   Estimation of potential for reduction of peak power demand in buildings (single-family houses) and district heating installations in order to optimize the LTDH system.

5. **Other investigated issues**
   Different other issues regarding LTDH potential to be investigated:
   - Steady state heat loss in pre-insulated pipes for low energy district heating
   - Design of LTDH network with supply water recirculation
   - A direct heat exchanger unit used for domestic hot water supply in a single-family house supplied by LTDH.

As it is seen the subtask are of very different character, so there will be conclusions for each chapter instead of one overall conclusion.

2 Examples of sites in Aarhus and Høje Taastrup for low-temperature district heating

This chapter shows examples of different possible future demonstration sites, which have been discussed in this project. Common for two of the considered sites is that they involve a larger amount of houses than the demonstration in Lystrup. Further it is interesting to demonstrate, that low-temperature district heating (LTDH) can be used in housing areas with existing buildings.

The first example is newly built in Solbjerg near Aarhus. This residential area is still on a planning level and it is still considered, whether the area should be connected to the nearby district heating network (DHN).

The two other examples deal with existing buildings. One of them is an older existing single-family house neighbourhood in Tilst near Aarhus and the other site is in the area called Sønderby in Høje Taastrup. Here it is also existing single-family houses, but they are newer. The main difference between the two areas is that one neighbourhood is primarily heated by radiators, and the other has floor heating. Both neighbourhoods are actually pointed out to be demonstration sites in a new EUDP-project [3], which is a result of the preliminary investigations and discussions in the current project.

2.1 Low-temperature network to a new residential area in Solbjerg near Aarhus

2.1.1 Description of the area and the study

A new building area is planned in Solbjerg near Aarhus. On this occasion AffaldVarme Aarhus (AVA) has made a study of the possibilities for district heating (DH) assessed in correlation to the building regulation BR08 [4] with more strict demands on energy consumption. See appendix 1.

The new area is called "Solbjerg Hedevej" and is planned to consist of 104 single-family houses, when the area is fully developed. The district/local plan defines that the houses must be Low-energy class 1 houses (BR08).

Figure 1 - "Solbjerg Hedevej" - the new area for low-energy houses.

The aim of the study was to investigate the heating peak load demand (kW per house) and to see if it is profitable with DH compared with other heating sources (heat pumps). For the calculations in the study, the commercially available program TERMIS was used. The assumptions used in the calculations are mentioned below. The assumptions are based primarily on the previous EFP2007 project [2] and Heating Plan Denmark 2010 [5].

2.1.2 Energy demand and peak load demand

The heating demand is calculated with regard to the energy frame in the Danish building regulation BR08 for low energy class 1 and 2 dwellings, which corresponds to 50 % and 70 % respectively of the energy demand in standard dwellings (referring to BR08). The annual maximum energy demand is seen in the table below. Please note that low-energy class 2 has become the standard in the new building regulation BR10 [6] and low-energy class 1 in BR08 is almost identical with the low-energy class in BR10.

Table 1 - Heat consumption in a 170 m² single-family house, low-energy class 1 and 2 respectively

170 m² single-family house	Low-energy class 1	Low-energy class 2
Space heating	3,632 kWh/year	6,682 kWh/year
Hot tap water	2,228 kWh/year	2,228 kWh/year
Total energy demand	5,860 kWh/year	8,910 kWh/year
Supply peak power for space heating	2.93 kW	4.46 kW

The supply peak power is calculated on the basis of the annual heat demand and an annual utilisation time of 2000 hours.

2.1.3 Calculation scenarios

The traditional dimensioning method for DH networks has in the study been challenged in order to get maximum use (optimisation) of the pressure capacity in the pipe network at 6 bar(g).

The network is dimensioned in TERMIS on basis of peak load and a differential pressure of 5 bars. The excess pressure will optimize the pipe dimensions. The aim in the study was to investigate the difference between the traditional DH system design and a fully optimized design. It is assumed that a higher extend of optimization will increase the challenges with the system operation. The maximum reduction of yearly heat loss in the pipe network shall be determined for various calculation scenarios. It shall be looked at how much the traditional dimensioning method / design could be changed in order to reduce heat loss in the pipes, so the district heating system still is reliable and environmentally economically cost-effective for a low-energy building area.

Assumptions for calculations:

- Max. design flow temperature: 90º C
- Yearly average flow temperature: 60º C
- Design return flow temperature: 35º C
- Yearly average return flow: 30º C
- Minimum flow temperature at the consumer: 55º C
- Soil temperature: 1,8-16,5ºC
- Pipe dimension (branch pipe): Minimum 10 mm (internal)
- Branch pipe length: 15 m
- Pipe types: Twin pipe in insulation class 2 (series 2)
- Max. flow speed in all pipes: 2 m/s
- Simultaneity factor: According to "Varmeståbi" [7]
- Size of houses: 170 m^2
- All houses in the area is assumed to be connected
- 6 bar-system
- The peak heat load in autumn is the design load for the pipes. The autumn load is equivalent to 60% of the total heat load and the fully domestic hot water (DHW) load
- Bypass temperature set point: 56,5ºC (at consumer)
- Band width 2,5º C
- Yearly usages time: 2000 hours
- Max. 6 bar(g)system
- Traditional DH design
    - Max. 50Pa/m (5 mmH_2O/m) pressure drop in main pipes
    - Average connectivity effect 8 kW
    - Minimum temperature difference 30° C
    - Minimum pressure differential 0,3 bar
    - Simultaneity factor: According to "Varmeståbi" [7]
    - Minimum flow temperature at the consumer 60º C
    - Max. temperature in return pipe at the consumer 40° C
    - Twin pipes

The following consumer installations are used:

- **GVV unit, 32.3 kW**: 32.3 kW heat exchanger (DHW), which according to the standard DS439 [8] should be able to cover consumption from a shower and a kitchen sink in use at the same time.
- **GVV unit, 20 kW**: 20 kW heat exchanger (DHW), which corresponds to the heat flow rate for a shower
- **FVB unit**: 110 litre district heating storage unit, which is a new type of unit, where the hot water storage is on the primary side. The storage will level out the heat demand during the day, which can make the pipe dimensions smaller and thereby reduce heat loss in the network.
- **VVB unit**: Traditional district heating unit with hot tap water storage.

Scenarios:

A. Low-energy class 2 houses with "GVV unit 32.3 kW" + traditional DH design

B. Low-energy class 2 houses with "GVV unit 32.3 kW" + 2.7 kW heating supply

C. Low-energy class 2 houses with "GVV unit 20 kW" + 2.7 kW heating supply

D. Low-energy class 2 houses with "FVB unit" + 4.5 kW heating supply

E. Low-energy class 1 houses with "VVB unit" + traditional DH design

F. Low-energy class 1 houses with "GVV unit 32.3 kW" + 1.8 kW heating supply

G. Low-energy class 1 houses with "GVV unit 20 kW" + 1.8 kW heating supply

H. Low-energy class 1 houses with "FVB unit" + 2.93 kW heating supply

I. Low-energy class 1 houses with "VVB unit"

Scenario A and E is marked with grey because they are the reference scenario for low-energy class 1 and low-energy class 2 respectively.

In all calculation scenarios the branch pipes are dimensioned with the twin pipe dimension Ø16/16/110 mm except for scenario A, which is dimensioned with the twin pipe dimension Ø20/20/125.

The figure below shows the dimensioned pipe network.

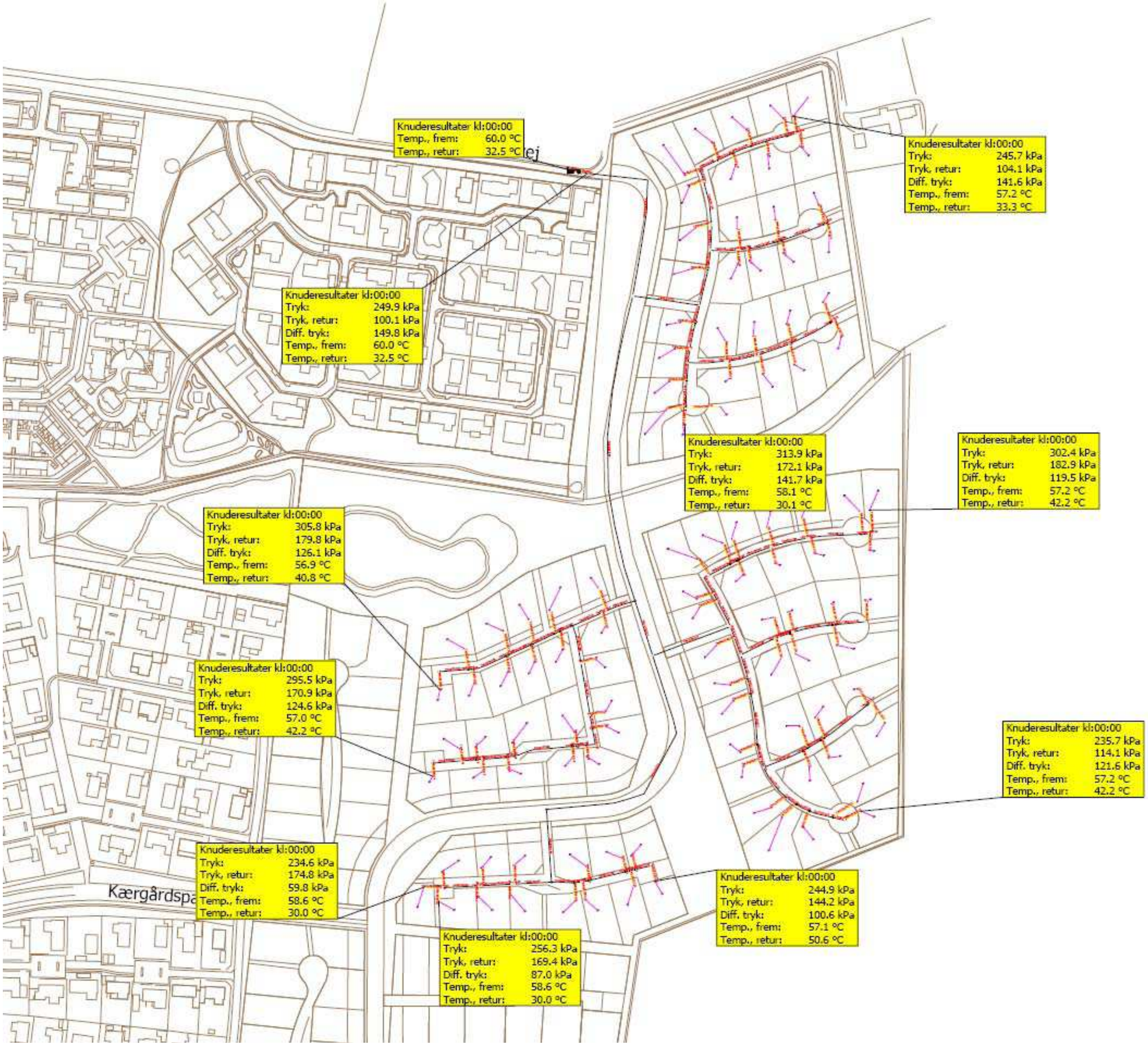


Figure 2 - Dimensioning in TERMIS of the pipe network in the low-energy house area.

Construction costs:
In each scenario the constructions of the pipe network includes pipes, pipe components and construction works. Costs to pumps, pump station buildings and network control equipments are not included. It should be noticed that for scenario D and H there is added 8,000 DKK per house to cover extra costs for the district heating unit.

2.1.4 Results

This subchapter shows the results of the study with the above given assumptions. The cost savings for scenario B-D are compared with the reference (traditional DH design) scenario A. And the cost savings for scenario F-I are compared with the reference (traditional DH design) scenario E. The cost savings takes both the total construction cost and the operation costs for a 20 year period into account.

Table 2 - Calculation results for district heating network to the low-energy house area.

Scenarios		Total heat supply to network [kWh]	Heat loss in network [kWh]	Heat loss in network [%]	Heat loss in network [kr]	Pump energy (electricity) [kWh]	Pump energy cost [kr]	Operation cost [kr./year]	Cost savings compared to traditionel DH design
A	Low-energy class 2 houses with "GVV unit 32,3 kW" + traditional DH design	1.006.338	199.930	19,90%	58.380	2.753	3.304	61.683	0%
B	Low-energy class 2 houses with "GVV unit 32,3 kW" + 2,7 kW heating supply	982.415	176.007	17,90%	51.394	3.998	4.798	56.192	12%
C	Low-energy class 2 houses with "GVV unit 20 kW" + 2,7 kW heating supply	977.307	170.899	17,50%	49.903	4.740	5.688	55.591	13%
D	Low-energy class 2 houses with "FVB unit " + 4,5 kW heating supply	960.704	154.296	16,10%	45.054	4.495	5.394	50.448	11%
E	Low-energy class 1 houses with "VVB unit " + traditional DH design	730.984	192.163	26,30%	56.112	2.936	3.523	59.635	0%
F	Low-energy class 1 houses with "GVV unit 32,3 kW" + 1,8 kW heating supply	712.843	174.023	24,40%	50.815	3.806	4.567	55.382	8%
G	Low-energy class 1 houses with "GVV unit 20 kW" + 1,8 kW heating supply	710.534	171.714	24,20%	50.140	4.897	5.876	56.017	8%
H	Low-energy class 1 houses with "FVB unit" + 2,93 kW heating supply	704.551	165.731	23,50%	48.393	4.960	5.952	54.345	6%
I	Low-energy class 1 houses with "VVB unit"	710.534	171.714	24,20%	50.140	4.855	5.826	55.966	8%

The district heating network in Solbjerg is in the calculation program TERMIS split in small sections with 225 nodes. The network is dimensioned on the basis of a peak load of 6 bar system. The pipe dimensions are reduced further in sections with excess pressure. This is also the reason why the heat loss is higher in scenario G and H compared to scenario C and D. The maximum pumping head in scenario G and H is 2 mH_2O higher than in scenario C and D.
The results are therefore accepted, since the project´s aim is to define the maximum limit of energy savings between the traditional installations and fully optimized installations. The heat loss will obviously be reduced in scenario for G and H (class 1 houses) by adding multiple nodes in a TERMIS model and calculating with the same pumping head. However, the heat loss is limited in already optimized installations.

As expected, the low-energy class 2 houses require a higher heat supply. But it is seen that the network heat loss and operation cost is almost the same as for the low-energy class 1 houses. Though, between the reference scenarios (A and E) the difference is larger.
The traditional DH design (scenario A and E) is in resulting in a larger network heat loss and operation costs, but these scenarios require less pump energy despite of the larger heat consumption (loss). The reason to this is that the LTDH network is designed with smaller pipes, which requires more pump energy but has less heat loss.

Scenario D and H has the lowest network heat loss and operation costs because it with the FVB unit is possible to lower the peak load heat demand (kW), which leads to smaller pipe dimensions and therefore lower heat loss.
A simple calculation of the costs savings for a 20 year period shows that for low-energy class 2 houses the savings with low-temperature DH would be about 11-13% compared to traditional DH. The savings for low-energy class 1 houses supplied with LTDH would be 6-8% compared to traditional DH. Further it is seen that the difference between GVV, FVB and VVB is quite small both for the low-energy class 1 and 2 houses.

The heat loss could be reduced even more with a lower DH temperature (50°C at the consumer) and usage of better insulated twin pipes (series 3). This would reduce the operation costs even more. It should be noticed that then it will not be possible to use VVB because of the risk of bacterial growth (Legionella). And GVV could be preferred because of lower purchase cost.

The CO_2 saving potential for low-energy class 2 houses with LTDH would be about 7.5 ton CO_2/year about compared to traditional DH. In case of low-energy class 1 houses the saving potential with LTDH would be about 4.4 ton CO_2/year compared to traditional DH.

Many low-energy houses are today constructed with individual heat pumps. Most standard house companies (typehus firmaer) already have a low-energy concept, which includes heat pumps, because it is considered as the cheapest heat installation. But in the previous research project EFP2007 [2] was a socio economic and environmental comparison made between LTDH and individual heat pumps. It showed that LTDH is fully competitive with heat pumps. Therefore AffaldVarme Aarhus is taking contact to the standard house companies in order to try to convince them about considering district heating and to make DH concept for low-energy houses.

2.1.5 General conclusions by AffaldVarme Aarhus regarding district heating to low-energy houses

For AVA the investigation has led to some considerations and conclusions.

A theoretically optimised DH network requires control after:

- Specific heat demand at each consumer
- Knowledge about the simultaneity factor in the network
- Complicated management units in the network (critical route changes constantly)
- Other conditions in network, which if not specified and known yet

Temperature in the DH network:

- A constant summer and winter DH temperature → Requires more simple control, but leads to a relatively large heat loss in the network.
- Varying the DH temperature over the year with current requirements for the consumer heating installation (substation) → Requires more advanced control but less heat loss in the network.
- Varying the temperature over the year with tougher requirements to the consumer heating installation (substation) → Requires even more advanced control but even less heat loss in the network.

To do list for AVA in order to disseminate the LTDH concept and ensure that the correct conditions are present:

- Decide requirement for the DH units (in-house substations)
- Decide if the supply conditions should be different for dense-low and open-low settlements
- Decide if LTDH shall be introduced as standard
- Put up requirements for new building areas
- Point out areas where DH should be offered

- Decide the heating tariffs. Should the tariffs be different for low-energy houses and for LTDH? It is important with high connectivity to be able to offer competitive heating prices (compared to heat pumps etc.).

The business economic is an important factor when DH to low-energy houses are considered.

The following has influence on the economy for the DH company:
- The number/share of consumers which will be connected to the network
- Heating tariff structure
- Construction costs (incl. depreciation, re-investments, interest rate)
- Construction costs to main pipe extensions
- Operation costs

The operation costs are defined by.
- Concentration of houses (heat density)
- Branch pipe lengths
- Temperatures in the district heating system
- Pipe dimensions
- Choice of consumer unit (installation) for domestic hot water production
- Performance of control system

The operation costs consist of costs to heat loss and electricity (pumps etc.).

2.2 Existing district heating network in Tilst near Aarhus

Denmark's largest single-family house neighbourhood is called Skjoldhøjparken and is located in Tilst near Aarhus. The neighbourhood consists of 1013 existing houses gathered in Skjoldhøjparkens Homeowner's association. The houses are built in the 70'ties and they are quite similar. Half of Denmark's single-family houses are from 1960-70, so this neighbourhood is pretty representative for existing single-family houses across the country.
AffaldVarme Aarhus (AVA) renovates continually the existing DH network, where the pipe components are outworn and the pipe insulation is inadequate. Several streets in Skjoldhøjparken are included in the renovation plans for the years to come. In that context, 8 houses on a street, Langøvænget No. 1-15, was investigated in order to assess the condition of the heating systems and the building envelopes with regard to energy efficiency. The houses are all connected to AVA's DH network.

Figure 3 - Typical seventy single-family house at Langøvænget in Skjoldhøjparken

AVA have had dialog with the house owners about potential improvement initiatives, which could create energy savings and higher energy efficiency. A few improvements like replacement of a couple of windows have been carried out. The house owners have been offered a subsidy scheme by AVA, who is interested to see if that will make the house owners invest in energy improvements measures. During the life time of the houses not many improvements or notable maintenance have been carried out, so the potential for energy savings are quite large.

The investigation work on the 8 houses at Langøvænget is an offshoot of another project, executed by the real-estate company, Realea. In that project four houses in the neighbourhood were renovated with regard to energy efficiency. One of these four houses is among the 8 houses on Langøvænget. The Realea project began in September 2008 with the acquisition of the four houses, which then were rented out to four test families for a three year period. And an architectural competition was organised in the projects start-up phase. Immediately after the families did move in (November 2008), a "before" measurement of energy and indoor climate was carried out. The measurements were done by Aalborg University during the heating season in 2008-2009. Then the energy renovations were carried out in the houses from August to December 2009. Directly hereafter the "after" measurement of energy and indoor climate was done in order to document the effect of the improvements. A progress project report was delivered by Aalborg University in summer 2010 [18] and it had the conclusion that energy improvement measures are profitable up to a certain point.

Anyhow, profitable improvements for the house owners are not everything. AVA has interest in combining energy improvements of the houses with improvements of the district heating network in order to get an optimised energy system, which is future-proofed - demand for energy resources is reduced and the system shall be suitable for heat supply from renewable energy sources (low DH temperatures). In other word a good system for an environmental, supply and economic related point of view.

The first step by AVA to optimise the district heating system is to install a mixing shunt during spring 2011 for the pipe network to the 8 houses. With the shunt it will be possible to lower the temperature in the pipes for the street. The supply temperature will be changed several times during the year. Throughout monitoring it will be looked at closely if the new district heating supply conditions will lead to any heat problems for the occupants of the houses. Later in 2011 the pipes are expected to be replaced with new well insulated twin pipes, which will give rise for further energy saving potential. Even that the project only includes 8 houses, the concept and experiences can be used all over the neighbourhood and in similar single-family house areas.

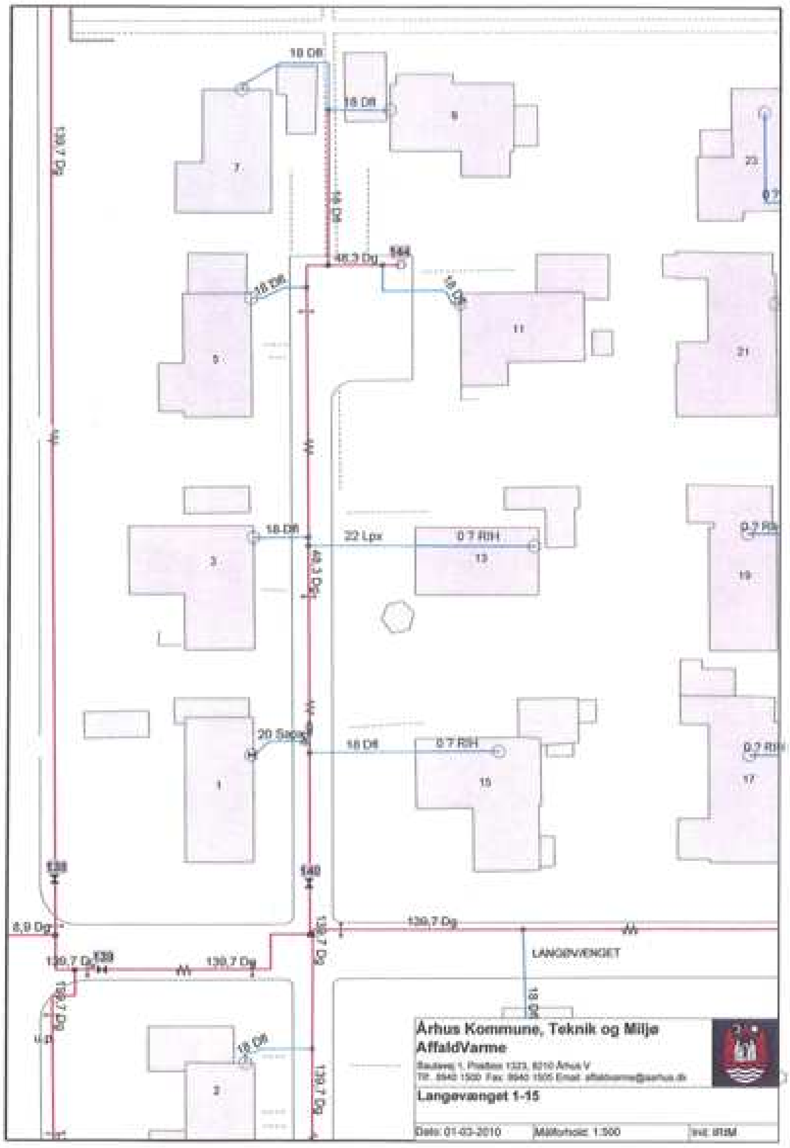


Figure 4 - Existing district heating network for the 8 houses in Langøvænget, Skjoldhøjparken, Tilst.

In the process for the 8 houses, AVA has offered the house owners a free inspection of the DH installation by a plumber. All house owners took that offer and the inspections were carried out in January and February 2010. On basis of the original building drawings heat loss calculations for the houses were done and compared with the installed radiator capacity. This was done to investigate directly if it is possible to lower the DH supply temperature in the pipe system of the street and how much. The mixing shunt will be controlled after the house with the most critical radiator capacity. The inspections showed surprisingly that the radiator system is undersized in several of the houses. See table below. Some of the houses with undersized radiator system use a wood stove to ensure enough heating during cold days.

Table 3 - Results from the inspection of the 8 houses with focus on the heating system (2009).

House	Year of construction	Area m²	District heating consumption incl. hot water		Other heating sources	Calculated heat loss W	Installed radiator capacity at 70/40°C W
			kWh/year	kWh/m²/year			
A	73/2009	130	16,250	125	No	7,600	7,541
B	73/78	162	13,437	83	wood stove	9,180	12,355
C	73	108	11,454	106	?	7,045	7,685
D	73/76	133	18,689	141	?	9,261	6,773
E	73	115	16,000	139	wood stove	8,032	5,050
F	73	120	7,323	68	wood stove	7,949	5,923
G	73	108	12,180	113	?	7,183	5,623
H	73/76	178	13,139	74	wood stove	11,058	7,934

The total DH consumption for the 8 houses is 108,500 kWh and in average 13,560 kWh per house.

The house owners were offered individual presentation of the inspection report results and a talk about the possibilities for subsidy to implement energy savings. To motivate the house owners AVA also presented thermo graphic pictures of the houses. The house owners were offered 50% subsidy to improvements of the heating system, which could give better cooling of the district heating water. Also the house owners were offered subsidy to improvements of the building envelope. The specific offer was to cover the cost difference between a "standard improvement" (300 mm ceiling insulation, 2-layer windows and 200 mm crawl space insulation) and an "optimal improvement" (400 mm ceiling insulation, 3-layer windows and 300 mm crawl space insulation).

The general conclusion from the investigations and the process so far is that some houses has a undersized radiator system, almost all houses have done very little to improve the energy efficiency. And despite of the subsidy offers by AVA, it has not been possible to motivate the house owners to make investments in order to achieve energy savings.

For AVA it has been surprising that the heating system is insufficient in some of the houses. In the technical terms for the district heating delivery, AVA guarantees only 60°C in supply temperature all year around. In the street the DH is delivered with a much higher temperature most of the year, but if AVA didn't do that the houses or some of them would have serious problems with the heating during winter. This is a lesson learned by AVA and indicates that implementation of a LTDH concept with lower DH temperatures and smaller pipe dimensions doesn't make sense if the houses not are prepared for these terms.

It is not optimal that some houses in a district heating area are dependent of wood stoves. Therefore it is not an obvious demonstration site for LTDH, but it shows very good the challenges, which can occur. By installing extra radiator capacity and maybe replacing /

upgrading some windows and doors, the houses can settle for DH as heating source and the houses are better qualified for LTDH.

In connection with the preparation of the mixing shunt and the replacement of the existing DH pipes in the street AVA carried out a study to investigate the saving potential for the lower DH temperatures. The first table shows the heat supply for Langøvænget as it is more or less today with a constant supply temperature at 80°C all year around.

Table 4 - Calculation of heat demand, heat loss and heat supply in the existing DH pipe network in Langøvænget 1-15. Constant supply temperature at 80°C.

Period No.	Temperature interval °C	Time h	Heat demand kW	Supply temperature °C	Heat loss in pipe network	
					%	kWh
1	<-4	157	51.81	80	9.5	848
2	>=-4 - <-2	225	41.45	80	11.35	1,215
3	>=-2 - <2	2,016	21.79	80	19.3	10,483
4	>=2 - <7	1,795	10.36	80	32	8,437
5	>=7 - <13	1,952	5.18	80	46.5	8,003
6	>=13	2,609	5.18	80	46.5	10,697
Yearly total		8,754			27.69	39,683

The figure below shows an optimised operation plan, which could be used to lower the heat loss in the pipe network.

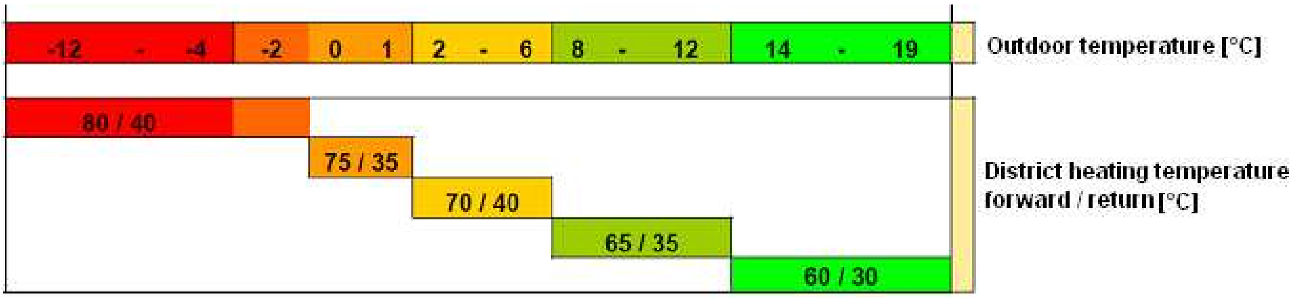


Figure 5 - Optimised operation plan for Langøvænget.

The next table shows the heat supply controlled after the optimised operation plan.

Table 5 - Calculation of heat demand, heat loss and heat supply in the existing DH pipe network in Langøvænget 1-15. Varying supply temperature at set after an optimised operation plan.

Period No.	Temperature interval °C	Time h	Heat demand kW	Supply temperature °C	Heat loss in pipe network	
					%	kWh
1	<-4	157	51.81	80	9.5	848
2	>=-4 - <-2	225	41.45	80	11.35	1,215
3	>=-2 - <2	2,016	21.79	75	17.9	9,475
4	>=2 - <7	1,795	10.36	70	27.6	7,000
5	>=7 - <13	1,952	5.18	65	37.3	6,051
6	>=13	2,609	5.18	60	34.3	7,044
Yearly total		8,754			23.39	31,634

From the table it is seen that it is possible to reduce the heat loss in the pipe network from 27.7 to 23.4% just by lowering the DH temperature when the outdoor temperature allows it.

Actually, the DH temperature can be lowered most of the year. The heat savings is about 8 MWh, which corresponds to 20% of the total heat loss for the street with the 8 houses. This corresponds to a CO_2-reduction of 1.3 ton per year.

Upgrading of the pipe system with twin pipes would ensure an even larger saving potential.

By upgrading the houses heat installations (radiators) or improve the building envelopes it will be possible to lower the DH temperature further down to 55/30°C and reduce the heat loss additional. Further investigations on lowering of supply temperature for one of the houses from Langøvænget are reported in chapter 4.

See also the article (in Danish) in appendix 2.

2.3 Existing district heating network in Sønderby, Høje Taastrup

The existing single-family house neighbourhood Sønderby in the area Torstorp in the southern part of Høje Taastrup has been identified as ideal demonstration site for the concept for the low-temperature district heating (LTDH) concept. The neighbourhood consists of 75 houses from the 1990s with floor heating in all rooms. The figure below shows the 75 houses.

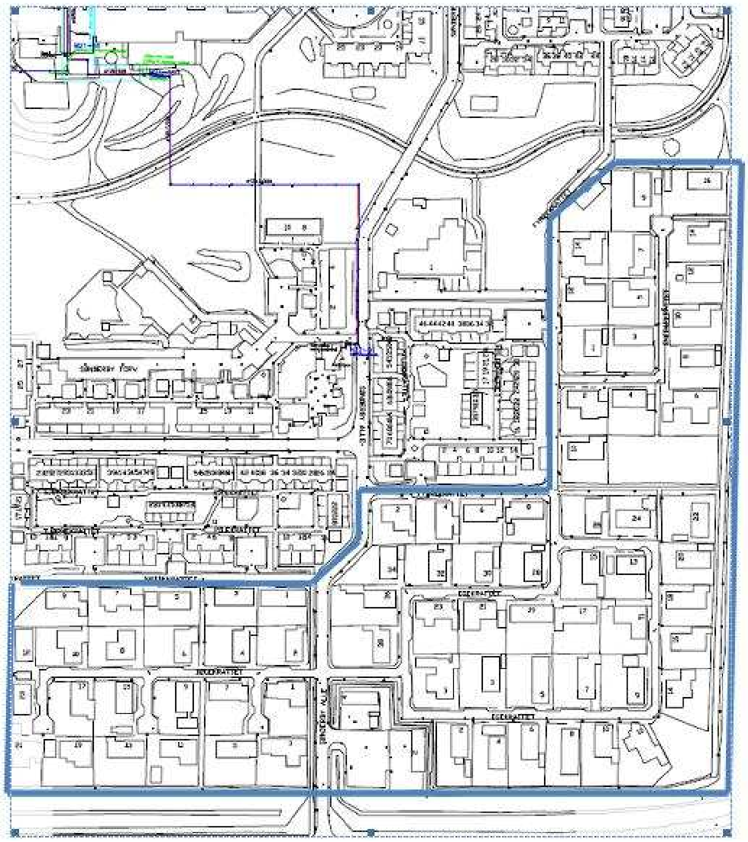


Figure 6 - Oversigt over parcelhuskvarteret Sønderby i Høje Taastrup.

All houses are connected directly to a private district heating network, supplied by Høje Taastrup Fjernvarme (HTF), the DH company in Høje Taastrup, via a heat exchanger central. The houses and the existing district heating network is only about 15 years old, but the existing PEX pipe DH network is assumed to be in a poor condition, because the annual heat loss is more than 40%. The picture below shows a typical house in Sønderby.

Figure 7 - Example of a single-family house in Sønderby.

The 75 houses are gathered in a homeowner's association and have received an assembled offer from HTF about to be connected directly, so each house becomes individual costumer. In connection with that, it was seen as a good opportunity for the homeowner's association to become a part of the EUDP project, where LTDH should be demonstrated in existing buildings. Implementation of the LTDH concept will result in replacement or upgrading of the local district heating network and the consumer installations. Thereby, the heat loss in the network will be reduced significant and the consumers can expect lower heating costs. Moreover the CO_2-emission will be reduced and the cooling of the DH water be optimized, so the return water will get a very low temperature.

Today, the houses have hot water tanks at either 110 or 150 litres, which in many cases is inadequate, because some houses have a bathtub. In many houses, the hot water tank also has a problem with calcification because of the high calcium content in drinking water. Therefore, many of the district heating units stand in front of replacement. A heat exchanger unit would be preferable instead of the DH storage unit (FVB), because of the smaller space requirement. A traditional DH unit with hot tap water tank (VVB) is not a solution, because the risk of Legionella bacteria, when having lower DH supply temperatures.

All houses have floor heating system. Since floor heating systems operates with low temperatures (compared to radiator systems) it is very suitable for LTDH. It is not unusual that older floor heating systems operates with a constant flow temperature at 40-45 ° C throughout the year. Some explanations here can be inability or improper balancing of the individual heating pipes and lack of feed temperature control. That is not expected to be the case in Sønderby, but it is important, that it is investigated and changed in order to achieve satisfying low return temperatures in the DH system. It is proposed to select some houses in Sønderby for analyzing and testing floor heating system control. In this context, a new prototype of floor heating manifold with dynamic balancing is considered to be demonstrated.

All houses shall be equipped with remote reading temperature and energy meters, which have become standard at HTF.

The figure below shows the variation in DH consumption in the 75 houses in Sønderby throughout the last six heating seasons. The average annual consumption is 12.7 MWh, but the variation is large. The lowest registered consumption is 3.6 MWh/year, while the largest consumption has been 23.3 MWh/year. The reason for the large variation is mainly that some houses have a wood-stove, which they have used because the DH price is high due to the large heat loss in the pipe network.

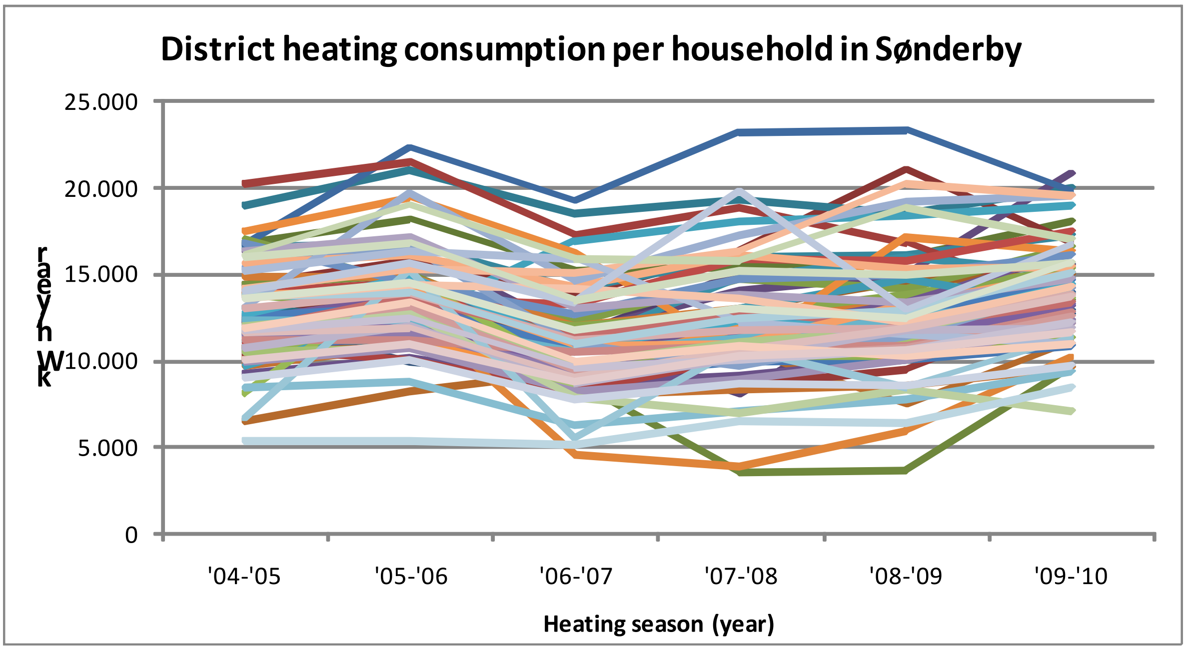


Figure 8 - Variation in district heating consumption in the 75 houses during six heating seasons.

The total for heating consumption for the 75 houses has in average been 955 MWh/year. With a heat loss in the network of 666 MWh/year corresponding to 41%, the total average heat supply to the private network is calculated to 1,620 MWh/year. This consumption corresponds to a CO_2-emission of 215 ton per year with the present emission factor for HTF.

Experiences with LTDH show that the heat loss in the network can be brought down to about 15% or less. If the heat loss for Sønderby is assumed to be 15%, it would make out 170 MWh, which 75 lower and corresponds to a heat reduction of 500 MWh per year. The CO2-emission will be reduced with 66 ton per year.

2.4 Conclusions

Below is listed the main conclusions for the 3 sites, where low-temperature is considered.

Solbjerg

- A new single-family house area in Solbjerg near Aarhus has been investigated.
- The area will have 104 low-energy class 1 houses, when the area is fully developed.
- A calculation model in the program TERMIS has been made for a LTDH network (60/30°C). Comparison between different heat demands, low-energy class 1 and 2 houses, and between different consumer unit types have been carried out.
- The cost saving potential for a LTDH network with low-energy class 1 houses is calculated to 6-8% compared with traditional DH. If the network was with class 2 houses the saving potential would be 11-13%. The larger saving potential is due to the higher heat demand in the class 2 houses.
- The CO_2-reduction potential with LTDH instead of traditional DH is assessed to be 4.4-7.5 ton per year.
- There is only a small difference in costs (construction cost and 20 years operation) between the different consumer unit types.
- Most standard house companies today only offer low-energy houses with heat pumps, though LTDH is considered to be a fully competitive heat supply solution. Throughout dialog and information AffaldVarme Aarhus is trying to change that.

Tilst

- 8 single-family houses from the 70's in Tilst near Aarhus have been investigated.
- The 8 houses is a part of Denmark's largest neighbourhood, which is called Skjoldhøjparken.
- Some houses have an undersized radiator system and use a wood stove as a supplementary heating source.
- Refurbish initiatives could reduce the heat demand and make the houses more suitable for LTDH, but it was difficult for the heating company to motivate the building owners to make improvements of the building envelope and heating installations in the despite of subsidy offers.
- An optimized yearly operation plan with lowering of the district heating supply temperature from 80°C down to 60°C in different parts of the year can reduce the heat loss in the existing pipe network for the 8 houses with 20%. That corresponds to a CO_2-reduction of 1.3 ton per year.
- An even larger potential can be achieved with replacement of the existing pipe system.

Sønderby

- A neighbourhood in Sønderby in Høje Taastrup has been investigated.
- 75 single-family houses from the 90's are connected directly to a private DH network, supplied by Høje Taastrup Fjernvarme.
- The private network is only 15 years old, but has a very high network heat loss on 41%.
- With LTDH it will be possible to reduce the network heat loss to 15% or lower.
- With LTDH the CO_2-emission can be reduced with about 66 ton per year.
- A new EUDP project will ensure that the existing network will be replaced and LTDH will be implemented.

3 Description of DH systems and potentials for energy savings and CO_2-reductions

3.1 Existing district heating systems

In order to evaluate the potential for low-temperature district heating (LTDH) one has to look at the existing systems.

3.1.1 Affaldvarme Aarhus

The district heating (DH) company in Aarhus, AffaldVarme Aarhus (AVA), supply today more than 50,000 direct private and trade costumers and many thousand building owners who account their DH consumption on behalf of their tenants. About 285,000 of Aarhus Municipality's 300,000 citizens are supplied with DH, so in total 95% is connected.

The district heating production for the transmission system comes from the basic load plants Studstrup and the incineration plant (AffaldsCenter), from the surplus heat and peak load and backup units boiler plant Gjellerup, boiler plant Jens Juuls Vej and boiler plant Århusværket. The supply security is higher today than earlier, because the production can come from different plants with different fuel types.

The transmission system consists of more than 130 km twin pipes with appurtenant pump plants, boiler plants etc. The heat mainly comes from the Studstrup plant and the incineration plant (AffaldsCenter) and is transmitted by high pressure and temperature to the heat exchanger plants. Here the heat is transferred via large plate heat exchangers to the distribution networks, where the pressure and temperature level is lower.

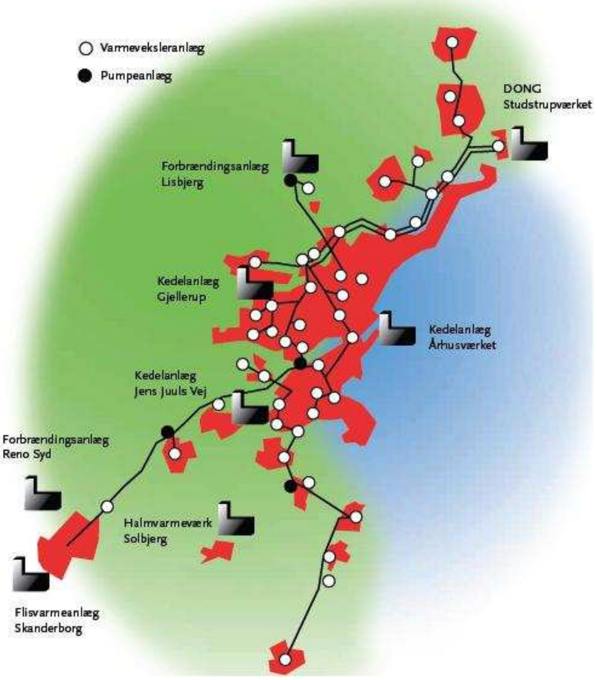


Figure 9 - Heat supply map of Aarhus.

Production plants, heat exchanger plants etc. in the transmission systems is monitored 24 hours a day via 70 intelligent substations connected in an it-network. Technicians use the network to operate and control the plants and for error detection. With heat forecasts heat production plans are being carried out to ensure optimal utilisation of the production capacity and to minimise the fuel consumption and environmental impact.

In 2009 the total pipe network length was 1888 km incl. branch pipes, which correspond to a pipe length of about 3,776 km. The climate adjusted heat consumption was 2,438,782 MWh and the network heat loss was about 16%. The average temperatures in distribution network were 77°C and 42°C for forward and return respectively. That gives an average cooling of 35°C.

Table 6 - District heating consumption for different consumer types, AffaldVarme Aarhus, 2010

Type of residence	Number of customers	Residential area m²	Commercial area m²	Total area m²
Farmhouses	343	59,690	1,594	61,284
Detached single-family houses	28,304	4,166,642	28,113	4,194,755
Terraced houses etc.	17,581	1,725,751	1,889	1,727,640
Blocks of flats	78,644	5,743,466	3,762	5,747,228
Dormitories	4,792	150,855	270	151,125
24-hour care centre (old people home, children home etc.)	361	67,994	27,436	95,430
Other permanent residence buildings	80	10,293	40	10,333
Total for residential incl. care centre	130,105	11,924,691	63,104	11,987,795
	94.8%	99.7%	3.8%	88.1%
Other buildings (commercial etc.)	7,115	30.476	1,593,638	1,624,114
	5.2%	0.3%	96.2%	11.9%
Total	137,220	11,955,167	1,656,742	13,611,909

It is estimated that about 7% of all heating installations are single-stringed radiator systems. Buildings with those installations are not directly suitable for LTDH.

AVA's present standard for new DH pipes and installations are:

- Twin pipes, insulation class 2 in dimensions up to Ø139
- Single pipes, insulation class 2, in dimensions above Ø139
- Direct heat exchanger units, normally with a 32kW heat exchanger unit for domestic hot water (private consumers).

3.1.2 Høje Taastrup Fjernvarme

Høje Taastrup Fjernvarme (HTF) supplies heat consumers in the Municipality of Høje Taastrup. The pipe network includes the network in Hedehusene, a town next to Høje Taastrup. All heat delivered to the network is purchased from the transmission company VEKS, to which HTF rent out peak load capacity. Thereby HTF is a part of the complex combined heat and power system, which covers the main part of Greater Copenhagen. VEKS purchases the heat partly from central combined heat and power plants and partly from waste incineration plants. The peak load capacity comes from 7 oil-fired heating plants.

HTF has about 5,300 heat customers, whereof the 300 are large customers, which in total purchases 73% of the DH in HTF's network. The 25% largest customers purchases 50% of the heat. HTF supplies in total 2.6 million square meters in different building/customer categories. See table below.

Table 7 - District heating consumption in 2009 for HTF's customers listed for different building categories

Building category	Number of customers	Building area m²	District heating consumption MWh	District heating consumption kWh/m²
Residence buildings	5,032	1,361,702	157,761	116
Public buildings	96	207,584	25,409	122
Commercial buildings	127	397,060	35,413	89
Industry buildings	43	472,131	54,000	114

The average DH consumption per customer for residence buildings are 31.3 MWh. That is a high consumption, but is caused by blocks of flats etc. which is registered as one costumer. In those blocks a separate accounting is made with all households.

District heating temperature conditions in HTF's pipe network:

- Average supply temperature approx. 80°C
- Average return temperature approx. 47°C
- Average cooling of district heating approx. 33°C

The figure below shows HTF's supply area. The existing pipe system is drawn with red and marked with yellow (the area of Hedehusene). The transmission system (VEKS) is drawn with blue. The areas marked with green are the present natural gas areas.

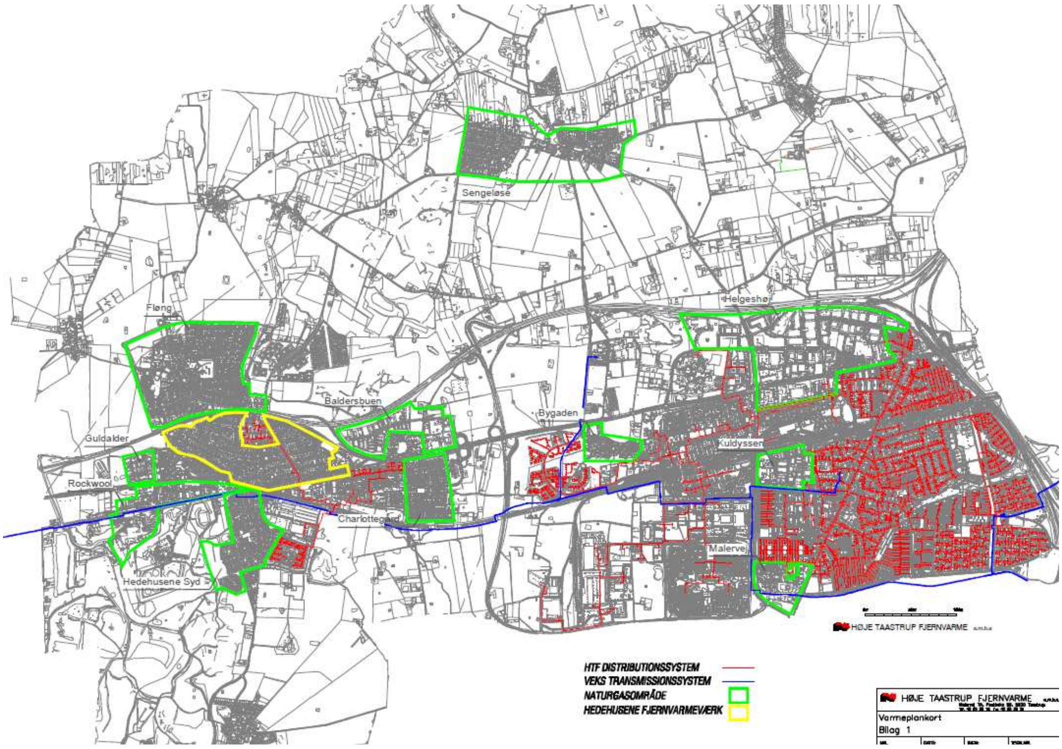


Figure 10 - Heat plan map for Høje Taastrup, which shows the existing district heating network and points out the areas with natural gas (green). The area marked with yellow is the district heating area of Hedehusene.

The length of the pipe network is estimated to 179 km. The figure below shows the heat purchase from VEKS and the total heat loss in the pipe network in the period 2005-2009. The pipe heat loss is estimated to about 15% of the total heat purchase.

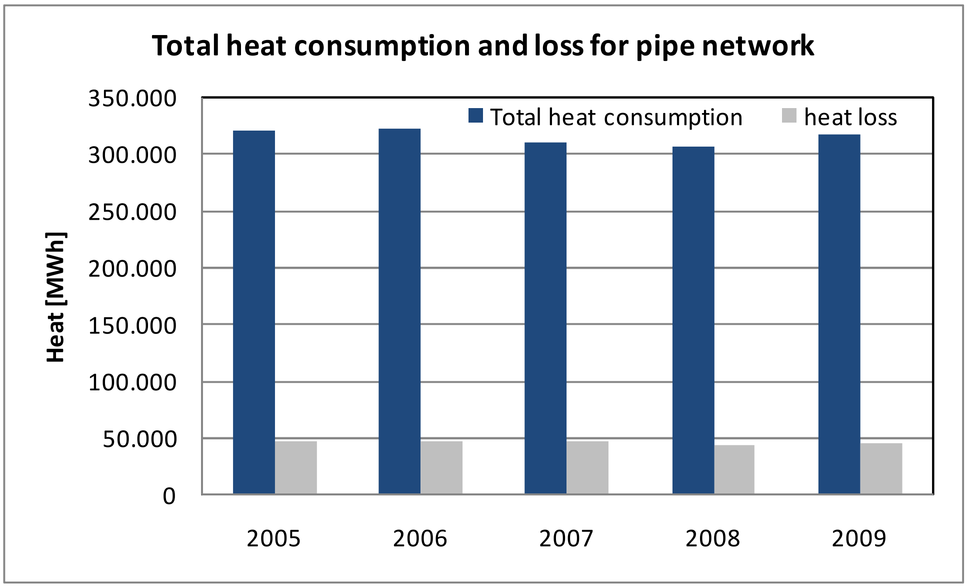


Figure 11 - Total heat purchase (heat consumption incl. heat loss in the network) and the heat loss in the pipe network for Høje Taastrup Fjernvarme in the period 2005-2009

The average age of the pipe network owned by HTF was in 2009 estimated to 16 years.

3.2 Development in the district heating supply

The DH systems in Aarhus and Høje Taastrup are continually being extended and improved. Furthermore, new heating plans state that the heat supply shall be CO_2-neutral within less than two decades. In general there are plans of new residential areas and implementation of renewable energy in the district heating systems.

3.2.1 Affaldvarme Aarhus

The existing DH system is expected to be extended. Both new build areas and existing housing areas with natural gas or oil boilers will be connected. At the same time the existing pipe system is continually being upgraded with newer pipes and AVA has focus on lowering the DH temperature.

Also, AVA has some energy saving initiatives levelled at the heat consumers and in cooperation with them:

- Guidance regarding DH installations and operation
- Subsidy for conversion from oil-fired boiler to district heating
- Subsidy to energy savings (improvement of buildings insulation and installations etc.)

AVA is like other energy companies committed by the Danish legislation to carry out a certain amount of energy savings every year.

The heat consumption is expected to increase with 194,843 MWh (at the heat exchanger station) until 2030 as a result of the network extension. Further it is expected that the conversion from individual natural gas and oil boilers will increase the heat consumption with 34,000 MWh until 2030. In the same period, energy savings carried out is expected to exceed the increased heat consumption caused by the extension and conversions. So the total heat demand is expected to decrease. Below is seen a heating forecast for the next 20 years.

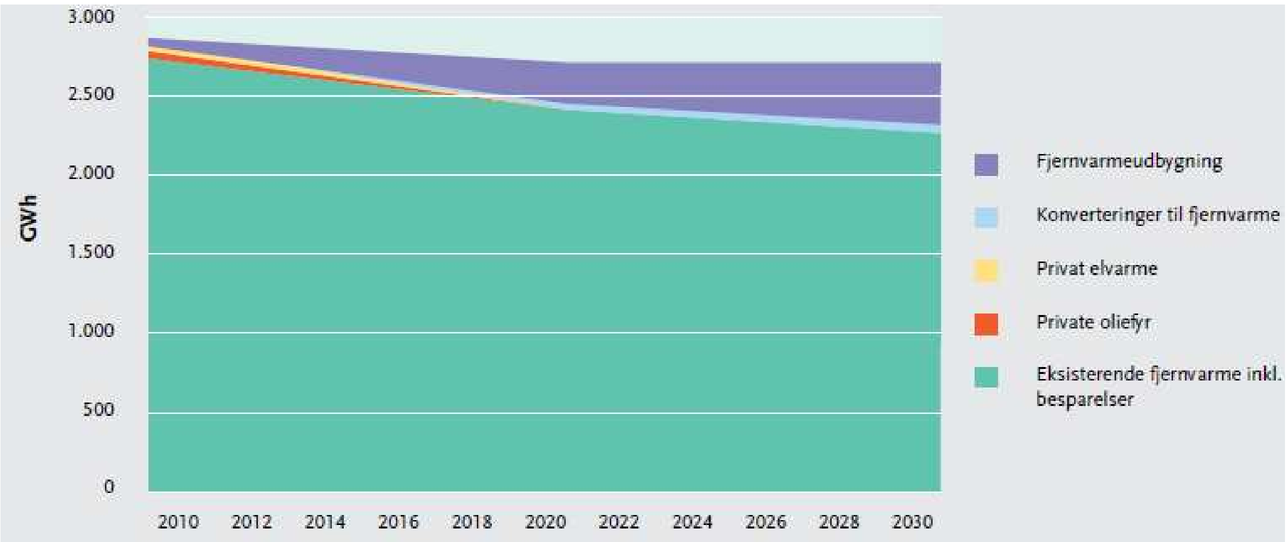


Figure 12 - Heating forecast for AVA based on the Danish Building Code 2010

The Heat Plan Aarhus [9] states that Aarhus shall be CO_2-neutral in 2030. This has been set as a goal by the City Council of Aarhus. It will result in implementation of large amount of renewable energy supply and surplus heat resources. AVA is starting to look at the possibilities for heat production from solar energy, wind energy and biogas. Also utilisation of surplus heat from industry in the harbour area etc is considered.

More close are the plans of implementing biomass in the heat supply system. The large Studstrup plant will be converted into a biomass plant, where wood pellets are used as fuel. Also a new biomass plant is planned to be built in Lisbjerg outside Aarhus. This plant will be a straw burning plant. The implementation of biomass will result in significant reduction in the CO_2-emission for the heat supply. See the graph below.

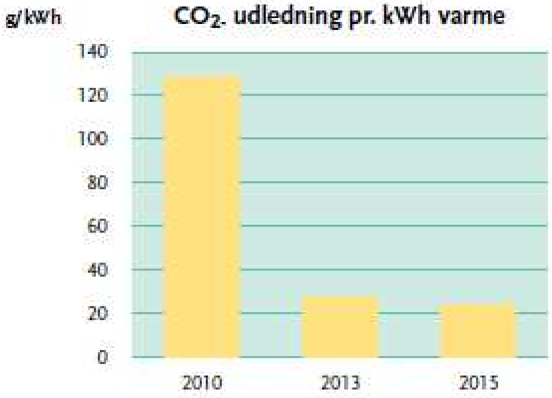


Figure 13 - The CO_2-emission per produced kWh heat (at the main heat exchanger) will decrease significant already in 2013, when biomass will be used in a large scale.

3.2.2 Høje Taastrup Fjernvarme

Like for AVA the existing DH system is expected to be extended both in new build areas and existing housing areas. HTF also continually upgrades the existing pipe system with newer pipes and has focus on lowering the DH temperature.

HTF's energy saving initiatives covers:

- Like other energy companies, HTF is committed by the Danish legislation to carry out a certain amount of energy savings every year. The saving goal is set to 2,700 MWh per year in the period from 2006 to 2013.
- The DH service scheme (FjR-ordningen)
- Installation of distant reading meters in all consumer installations in order to point out where in the pipe network the DH temperature can be lowered
- Guidance and subsidy to implementation of energy savings (renovation of building parts, heat installations and district heating pipe connections etc.)

Regarding new build areas in Høje Taastrup it is relevant to mention a new urban area called Gammelsø. This urban area is planned to be CO_2-neutral and is a part of the ECO-Life project, which has achieved funding by the EU's CONCERTO programme. The project will also demonstrate energy solutions in the suburbs of Hedehusene and Fløng. The vision for Gammelsø is to build low-energy buildings with a total floor area of 306,000 m^2. LTDH has been pointed out as the preferred heat supply. The heat consumption is assumed to be about 14 GWh per year. Including heat loss in the low-temperature pipe network the total heat consumption is expected to be about 16 GWh per year, which is estimated to be 6 GWh per year lower compared to a traditional DH system design.

As mentioned existing building areas are also in focus. Especially, an effort is put into conversion of natural gas areas. An investigation has been carried out in order to assess the potential for conversion of existing building areas into DH. In the following table existing natural gas areas in Høje Taastrup are listed. It is not know precisely how large share of the buildings is today connected to the natural gas network, but it is estimated to be about 80%. The rest have either oil-fired boilers (10%) or are electric heated (10%).

Table 8 - Building areas and heat consumptions in existing industrial and residential areas in Høje Taastrup.

Existing building area	Building area m²	Industry share	Residential share	Total heat consumption MWh/year
Baldersbuen	95,981	100%	0%	10,667
Helgeshøj	402,859	100%	0%	44,789
Guldalder	24,336	100%	0%	2,701
Hedehusene Syd	54,175	10%	90%	7,310
Charlottegård	40,836	6%	94%	5,560
Bygaden	28,192	48%	52%	3,541
Malervej	32,648	87%	13%	3,745
Kuldysen	85,149	100%	0%	9,468
Rockwool	104,143	100%	0%	11,550
Fløng	154,661	0%	100%	21,587
Sengeløse	102,733	0%	100%	14,250
Total	1,125,713			135,169

If all potential areas listed above are connected to the HTF's network (without any energy savings carried out in the buildings) the heat consumption will increase with 135 GWh per year plus the heat loss in the new pipe network. The 135 GWh corresponds to 43% of the existing heat consumption of HTF. It should be investigated if the industrial buildings are suitable for LTDH.

If only residential buildings are considered suitable for LTDH the potential increased heat consumption in the existing natural gas areas is about 50 GWh per year plus the heat loss in the pipe network. It corresponds to 16% of the existing heat consumption of HTF.

Table 9 - Building areas and heat consumptions in existing residential areas in Høje Taastrup.

Existing building area	Building area m²	Total heat consumption MWh/year
Hedehusene Syd	48,758	6,579
Charlottegård	38,386	5,227
Bygaden	14,660	1,842
Malervej	4,244	487
Fløng	154,661	21,587
Sengeløse	102,733	14,250
Total	363,441	49,971

It has to be mentioned that the potentials for increase heat supply is dependent of the number of consumers, who will connect to the DH network.

Also could be mentioned that HTF 1st January 2011 did acquire Hedehusene fjernvarme (the district heating company of Hedehusene). This will increase the yearly heat consumption of HTF.

In the Municipality of Høje Taastrup there is also an ambition of becoming CO_2-neutral, but no specific date have been given for it yet. So far the City Council has made a commitment to the following in the period of 2009 to 2013:

- Reduction of the electricity consumption and the CO_2-emission respectively with 2% per year compared to 2008 in the Municipal properties. In total it will be a reduction of 10%
- Put an effort into a reduction of the CO_2-emission with 2% per year compared to 2008 in the Municipality as a whole. In total it will be a reduction of 10%
- Planning and construction of a new CO_2-neutral urban area (Gammelsø) with 6-7000 inhabitants in the period forward to 2015

Very relevant when looking at CO_2-saving potentials for district heating in Høje Taastrup is also the plans for the heat supply by VEKS in the future. VEKS has an ambition of be able to deliver CO_2-neutral heat in 2025 and is planning solution. The table below shows the present and the expected CO_2-emission factors.

Table 10 - Present and expected CO_2-emission factors for district heating supply for VEKS and HTF respectively. The factor for HTF is higher because electricity consumption to distribution is included, so it is CO_2 per sold heat unit to the end consumers.

CO_2-emission factor	VEKS		HTF	
	kg/GJ	g/kWh	kg/GJ	g/kWh
2009	31.08	111.9	36.61	131.8
Expected in 2020	6	21.6	-	-
Expected in 2025	0	0	-	-

Solutions, which can lower the emission factor, are being investigated. Solar thermal plants, surplus heat from industry, biomass in CHP plants and geothermal energy are being considered for the heat supply of the future.

3.3 Estimate of energy savings and CO_2-reductions by using the low-temperature concept

The exact saving potential for LTDH in the present DH areas is difficult to assess, because of many different factors. There can be technical limitations in installations in houses, in heating plants and in the pipe networks. Quite an upgrade of the existing installations should be expected. A rough estimation of the saving potential for LTDH has been made based on the present DH consumption. The estimated potential is presented in this paragraph.

Today, 60% of all households in Denmark are connected to DH, but as mentioned earlier expansion is expected and is already planned for some areas either new housing areas or areas where "natural gas conversion" is taking place. This will increase the present district heating consumption and the saving potential for LTDH can therefore be even higher unless all expansion is made according to the LTDH concept.

The CO_2-reduction saving potential depends very much on the actual emission factors used in the calculation. The emission factors is expected to decrease over time, because of an increasingly implementation of renewable heat sources. So the calculated potential is only a momentary value.

Experiences from the demonstration in this project in Lystrup [1] and from the EFP2007 project [2] shows that the heat loss saving potential with LTDH can be up to 75%.
Reducing the DH temperature from 80/40°C to 55/30°C counts for 35%, while the pipe optimisation stands for the rest. The pipe optimisation includes (1) using twin pipes instead of single pipes, (2) having smaller service pipes and larger insulation thickness and (3) better insulation performance. The saving potential can vary depending on the heat density and it could be necessary with higher DH temperature than 55/30°C some places in the pipe network. So it is assessed that the saving potential for the network heat loss in total could be 50-75%.

Below is shown the used CO_2-emission factors.

Table 11 - CO_2-emission factors for 2009 for district heating consumption at the end-user

Locality	Emission factor kg CO_2 / MWh
Aarhus	165
Høje Taastrup	131.8
Denmark, average	150
Denmark, marginal	179

On basis of the emission factors and the consumption statistics for 2009, is calculated the CO_2-reduction potential with lLTDH instead of traditional DH. The potential is calculated for Høje Taastrup, AffaldsVarme Aarhus and for Denmark totally. See table below.

Table 12 - Heat loss in existing district heating system (2009 figures) and estimated energy saving potential and CO_2-reduction with low-temperature district heating

	Høje Taastrup Fjernvarme	**AffaldVarme Aarhus**	**Denmark in total**
Heat to network in 2009, GWh	317	2482	39,374
Network heat loss in 2009, GWh	44	522	9,430
Energy saving potential, GWh	22-33	261-392	4,715-7072
CO_2-reduction potential, ton CO_2 / year	2,900-4,350	43,065-64,598	707,175-1,060,763
CO_2-reduction potential	7-10%	11-16%	12-18%

From the table is seen that the CO_2- reduction potential for Høje Taastrup DH is between 2,900 and 4,350 ton per year corresponding to 7-10% of the total yearly emission. For AffaldVarme Aarhus the reduction potential is between about 43,000 and 64,600 ton, which is 11-16% of the total yearly emission. For Denmark in total it is assessed that there could be a reduction potential for LTDH of 707,175 to 1,060,763 ton, which is 12-18%. So, based on the present emission factor (2009) and the assumption of a heat loss reduction of 75%, it can be concluded that almost one fifth of the CO_2-emission in the DH supply in Denmark theoretically can be reduced if LTDH is implemented.

It shall be mentioned, that the heat consumption in the table not is degree days adjusted, but it is assessed, that it wouldn't change the saving potential much. What could have an impact, are changes in the heat supply and extension of the pipe network as mentioned in the previous paragraph (3.2). Implementation of more renewable energy in the heat supply would lower the CO_2-saving potential. But higher heat consumption, when new areas / heat consumers are added, will increase the potential if these systems not from the start are designed to low-temp DH.

As mentioned in the previous paragraph, it is expected that the DH supply in both Aarhus and Høje Taastrup will be CO_2-neutral within 15-20 years. To achieve that, it will be necessary to implement LTDH in order to be able to utilise all kind of renewable energy sources and to reduce heat loss in the pipe network. A low heat loss is essential for DH areas with low-energy buildings etc. Further with low-temperature DH, it will be possible to utilise return water from the existing DH system as supply.

Economy for LTDH compared to traditional DH hasn’t been looked at in details in the project, but the demonstration in Lystrup shows that it for new building areas not are more expensive to construct a LTDH network than a traditional DH network. Actually it can be cheaper to install a twin pipe system than a traditional single pipe system, but what pulls in the other direction can be more expensive in-house substations and control system.

Implementation of LTDH to existing buildings will require some technical adaption and therefore give raise for extra costs. The consumer unit needs to be changed or maybe it will be necessary just to change the heat exchanger for hot tap water. And then the room heating system needs to be appropriate. Buildings with floor heating are suitable for LTDH and doesn't need larger technical improvements, but buildings with radiators will need larger heating surfaces, which mean that larger or more radiators need to be installed. In some existing buildings you can say that some maintenance of the heating installations needs to be carried out anyway, but in general it will give raise to extra costs. It should be mentioned that in some buildings, the radiator system could be oversized, while it in other cases can be undersized. Instead of upgrading of the radiator system it is of cause also a possibility to improve the building envelope (insulation, windows, doors etc.). It is expected that it will be done

Most problematic is buildings with single-stringed radiator systems, because these installations require quite high temperatures and therefore not are suitable for LTDH.

The potential for implementation of LTDH in industrial areas is difficult to assess. Industrial buildings and areas have to be looked at individually in order to assess if LTDH is sufficient.

3.4 Conclusions

The main conclusions for this chapter are listed bellow, where the existing DH systems in Aarhus and Høje Taastrup are described and potentials for energy savings and CO_2-reductions for LTDH are assessed.

- The average yearly temperature is currently 77/42°C in AffaldVarme Aarhus' DH network. So there is a potential for low-temperature DH.
- The average yearly temperature is currently 80/47°C in Høje Taastrup Fjernvarme's DH network. So there is a potential for LTDH.
- The network heat loss in the DH systems is 15-16%.
- Residence buildings accounts for the major part of the heat consumption in AffaldVarme Aarhus' DH system.
- Residence buildings accounts for the largest part of the heat consumption in AffaldVarme Aarhus' DH system, but industry and commercial buildings also make up a great part.
- Both AffaldVarme Aarhus and Høje Taastrup Fjernvarme are continually extending and renewing the existing DH system. New built housing areas and natural gas areas etc. are being connected. Both heating companies pay attention to lower the DH temperature gradually.
- Both AffaldVarme Aarhus and VEKS (who deliver the heat to Høje Taastrup Fjernvarme) are planning to get a CO_2-neutral heat supply within 15-20 years.
- Lowering the DH temperature from 80/40°C to 55/30°C can reduce the network heat loss with about 35%. With an optimal pipe system the saving potential can be increased to 50-75%.
- The CO_2- reduction potential for Høje Taastrup Fjernvarme is between 2,900 and 4,350 ton per year corresponding to 7-10% of the total yearly emission.
- For AffaldVarme Aarhus the reduction potential is between about 43,000 and 64,600 ton, which is 11-16% of the total yearly emission.
- In total for Denmark the reduction potential for LTDH is assessed to be between 707,175 and 1,060,763 ton, which is 12-18% of the total yearly emission.

4 Refurbishment of buildings and implementation of low-temperature district heating

In this chapter possibilities for low-temperature district heating (LTDH) in connection with refurbishment of existing buildings and district heating (DH) network are investigated. Implementation of LTDH also for existing buildings is very important objective because major part of building stock is represented by existing buildings and growth of new buildings is only 1% per year. As an example, two typical single-family houses built in 70s were chosen. These buildings were originally designed with radiators operating on temperature levels 80/40/20°C and 70/40/20°C. We investigated how much supply temperature of DH can be reduced and how big influence will have basic renovation measure such a change of windows.

4.1 Measures for introduction of LTDH to existing buildings

Once a supply temperature to existing space heating (SH) system is reduced, the heat output of radiators is reduced as well and some action should be taken to keep desired thermal comfort. The actions can be changes performed on SH system to guarantee original power output but on lower temperature level (increase of nominal flow rate) or decrease heat loss/demand of the building. In many cases decreased heating output from radiators can be to some extent compensated by their original over-dimension caused usually by static dimensioning approach based on design outdoor temperature -12°C without considering thermal mass of the building. Additional possible over dimension is caused by the fact that radiators are usually placed below whole width of the windows to compensate down draught of cold air and usually from esthetical reasons radiators with the same height are used in whole flat. Nevertheless the level of over-dimension is usually not enough to cover reduced heating output caused by decreased supply temperature and thus smaller or bigger measures should be performed.

Possible solutions:

1) Reduction of heat loss/demand of building:

Refurbishment actions can be made in several “price levels”:

- Change of windows, which if not changed yet should be changed soon anyway because of their ending life-time
- More insulation on external walls or roof
- Installation of mechanical ventilation system with heat recovery

2) Modification of SH system:

SH system should be able to provide desired level of thermal comfort with lower supply temperature but at the same time with low temperature of return water. The optimal operation conditions should fulfil as much as possible both mentioned requirements.

For the first phase of introduction of LTDH in areas with existing buildings an increase of supply temperature during periods with low outdoor temperatures is assumed higher and more often than in areas with new buildings. For some existing buildings the increase in supply temperature will not be enough to provide thermal comfort and slight modifications of SH system should be taken. It means that some radiators will be changed to bigger ones. More precisely said it will be changed with radiators with bigger emitting surface (e.g. from one plate radiator to two plates). The bigger heating surface definitely doesn't mean increased energy consumption, it is just modification of SH system to deliver the same amount of heat as before but on lower supply/return temperatures.

The special attention should be paid in houses with one-string heating system. The one-string heating system has from its nature worse cooling of return water than two-string system and thus it is not favourable solution for LTDH. The solution for one-string system can be installation of thermostatic return valves on each radiator or complete renovation to two-string system.

Moreover in relation to domestic hot water (DHW) preparation, it is necessary to change DH substations with LTDH substations. The change should be made for existing instantaneous heat exchanger unit (IHEU, Danish abbreviation is GVV) as well for substations with DHW storage tank (Danish abbreviation VBV) because more efficient heat exchanger (HEX), designed especially for LTDH, is needed to provide DHW with desired temperature from DH with reduced supply temperature. For the houses with traditional substation with DHW storage tank (DHWSU) the change of substation is additionally required because traditional DHW storage tanks couldn't be used in LTDH because of Legionella risk. The existing substations can be still used if the district heating network (DHN) is never during a year operated with temperature below 55°C for IHEU and 60°C for DHW storage tank.

4.2 Case studies on existing buildings

4.2.1 Model houses and definition of cases

Two typical single-family houses from 70's were modelled in software BSim. We investigated how much supply temperature for SH system can be reduced in existing buildings in relation to performance of installed windows in order to introduce LTDH. The reason to choose windows renovation was based on the fact, that it is the easiest and cheapest measure reducing heat demand of the buildings. Moreover, the windows glazing has typical life-time of 30 year and thus for houses build in 70s is recently time to change glazing or whole window including frame. The parameters of windows for three simulated cases are shown in Table 13.

Table 13 – Definition of simulated cases – performance of windows

Case	Description	Overall window U-value [W/m2K]	
		Aarhus	Næstved
1	No measures taken	2.5	2.8
2	New glazing, old frames	1.4	1.4
3	New low-energy windows (frame included)	0.9	0.8

We are also reporting values of yearly heat demand and peak power for SH for individual cases. Both buildings are in detail described (in Danish) in Appendix 3 and 4. Moreover we also calculated flow rate needed for supplying of SH systems operating on different supply/return temperatures to check if it has some influence on dimensioning of DHN.

Method:

The method to find out lowest supply temperature for SH was based on gradual reduction of heat output of radiators in program BSim until drop of operative temperature in the house bellow desired value was observed. First, the minimal temperature level for SH system for the day with lowest outdoor temperature (-21°C, in the Design Reference Year, DRY, 8.1.2003) was found. Later temperature of heating water needed for SH system when outside temperature is around 0°C was found. A power provided by radiators for other than design conditions was calculated in software provided by producer of radiators.

4.2.2 Results

Aarhus

In Table 14, the heat demands, the temperature levels and corresponding peak power and flow rate for SH system for typical house from 70's, located in Aarhus, can be found for three different cases of renovation.

Table 14 – Energy demand for space heating, maximal power and needed supply/return temperature for space heating system in typical house from 70s in Aarhus, area 120m²

Case	windows properties U-value [W/m²K] g-value [-]	Energy demand for SH [MWh/year]	Peak power for SH [kW]	Temperature needed in radiators for:		Flow need for t_{out}=-21°C [L/min]
				Tout=-21°C	Tout=0°C	
1	U-value: 2.5 g-value: 0.43	10.49	5.8	70/40/20	60/29/20	2.75
2	U- value: 1.4 g- value: 0.43	8.3	5.0	65/35/20	60/26/20	2.36
3	U- value: 0.9 g- value: 0.35	7.55	4.5	65/32/20	52/25/20	1.93

It can be seen that change of windows from case 1 to case 3 reduces yearly heat demand for SH from 10.49 MWh to 7.55 MWh (considering today price of heat from DH for end-user 620 DKK/MWh (Kobenhavns Energy-2011) it result in yearly saving 1823 DKK/year). Moreover reduced heat loss of building allows operate SH system as well as DHN with lower supply temperature and thus considerable amount of heat loss from DHN can be saved. The maximal flow for SH system needed from DHN for outdoor temperature -21°C is shown in last column.

It can be seen that for house with low-energy windows (case 3) SH system can be during period with outdoor temperature above 0°C operated with supply temperature 52°C and for lowest considered outdoor temperature – 21°C with supply temperature 65°C instead of 60°C and 70°C as was necessary for original house with old windows (case 1). Reduction of heat demand is 28%.

The supply/return temperatures needed for SH system for outdoor temperature 0°C presented in Table 14 were designed in order to reach lowest possible return temperature from SH system back to DHN. An alternative is to operate SH system with lowest possible supply temperature and sacrifice low return temperature. Keeping the same power output from radiators while reducing supply temperature results in lower delta T on radiators and thus in higher flow rates. The flow rates needed for SH system operated on different temperature levels for outdoor temperature around 0°C are shown in Table 15.

Table 15 – Flow rates needed for SH system operated on different temperature levels for outdoor temperature -21°C and 0°C

Case	Peak power [kW] for -21°C	Temperature for SH	Flow [L/min]	Temperature for SH	Flow [L/min]	Temperature for SH	Flow [L/min]	Peak power [kW] for 0°C
		T_{out}=-21°C		T_{out}=0°C		T_{out}=0°C		
1	5.8	70/40/20	2.75	60/29/20	1.47	50/34/20	2.84	3.23
2	5	65/35/20	2.36	60/26/20	1.16	50/29/20	1.87	2.79
3	4.5	65/32/20	1.93	52/25/20	1.31	50/26/20	1.47	2.51

It can be seen that the SH system can be for outdoor temperature 0°C supplied with temperature 50°C even in case of not renovated house if return temperature from SH system 34°C is accepted.

Flow rate for operation of SH system during outdoor temperature 0°C with supply temperature 50°C is for house renovated to case 2 and 3 lower than flow rate needed for peak load for outdoor temperature -21°C. Only exception is case 1 when flow rate for 0°C is slightly higher than max. peak flow rate for outdoor temperature -21°C and thus DHN should be dimensioned with consideration of the highest flow rate. This consideration is important when designing new DHN for existing buildings.

The question is which from both presented solutions, i.e. use of higher supply temperature and low return with lower flow rate or lower supply, higher return temperature with higher flow rate is optimal for DHN. The optimal solution will depends on design of individual DHN (size of pipes) and type of heat sources available, i.e. if there are some RES in the network.

Næstved

Results of simulations for Næstved house can be found in Table 16. A yearly heat demand was by complete windows renovation decreased from 25.9 MWh to 17.2 MWh and thus SH system can be operated during coldest period on temperature level 70/33/20°C (case 3) instead of 80/40/20°C (case 1). It can be seen that dimensioned heat loss was decreased to one third (33%) of original value, i.e. from 12583W to 4180W. It is caused by fact that house has French windows in the living room accounting for considerable part of wall and thus new windows with lower U-value have great impact on reduction of heat demand.

Table 16 – Data for typical Danish house from 70s in Næstved, area 143 m²

Case	Dimensioned heat loss (-12°C) [W]	Energy demand for SH [MWh]	Energy demand for SH [kWh/m2]	Peak power for SH [kW]	flow rate from DHN for max peak load [L/min]	Temperature in SH system needed for	
						T_{out}=-21°C	T_{out}=0°C
C1 - Old windows	12 583	25.9	181	11.8	4.21	80/40/20	66/33/20**
C2 - New glazing	7 437*	19.5	136	9.7	3.28	75/33/20	52/33/20
C3 - New windows	4 108	17.2	120	8.3	3.18	70/33/20	49/33/20
C4 - New windows and radiators	4 108	17.2	120	8.3	3.79	64/33/20	45/31/20***

*House with new glazing still have big heat loss by infiltration because of leaky windows frames

** Value not simulated, based on simplified calculation

*** supply temperature of 45°C is not possible in reality because for DHW preparation supply temperature of 50°C is needed

The temperature level of supply water needed for proper operation of SH system can be additionally decreased by change of radiators in critical rooms (rooms which are defining temperature needed for heating system) with radiators designed for lower temperature operation, i.e. with bigger surface. The change of radiators (case 4) will allow use supply temperature around 50°C (i.e. 49/33/20°C) down to outdoor temperature -7°C (value is not included in the table).

The temperatures for operation of SH system with outside temperature 0°C for example of Næstved house were directly found with constraint of lowest possible supply temperature. It can be seen that for periods with outdoor temperature around 0°C SH of the house can be operated on temperature level 52/33/20°C if original glazing (case 1) was changed with new double-glazing (case 2).

Result summary

- The results show that improvement/change of the windows in the examined houses allows reduction of maximal supply temperature for SH system needed during coldest period ($t_{outdoor}$=-21°C). The extent of possible temperature decrease depends on building itself and level of over-dimension of heating system and cannot be generalized.

- For case of house in Arhus, SH system can be for outdoor temperature 0°C operated with supply temperature 50°C even before renovation if higher return temperature of 34°C is accepted. The special attention should be paid to see if decreased mean temperature of radiator has influence on thermal comfort in existing buildings.

- If the windows were changed at least in last 15 years (overall U-value lower than 1.4 $W/K \cdot m^2$) SH systems of both investigated houses can be supplied with temperature around 50°C for outdoor temperatures above 0°C. Due to DRY (design reference year) the outdoor temperature bellow 0°C occurs for 1258 hours during a year. The heating season for existing buildings is usually counted from 1st September to 31st May, i.e. 6588 hours. It can be calculated that outdoor temperatures bellow 0°C counts for 20% of heating period. During this period supply temperatures of DHN will be increased up to level needed for buildings with demand for highest supply temperatures.

- For outdoor temperature 0°C it is not possible operate original SH systems in existing buildings on desired temperature level 50/25°C, because for this desired temperature drop on the radiator the power output will be not enough. The solution how to supply such a SH systems with DH with supply temperature 50°C is to allow increase of return temperature to value around 30°C or increase size of radiators which will allow operate on temperature level 50/25/20.

- A heat output of the radiator is based on relation between supply and return temperature. For the same power output, the lower the return temperature is, the higher supply temperature should be and vice versa, nevertheless the flow rate needed for the radiator operated on higher temperature is lower. In case of Aarhus we focused on proper cooling of heating water in SH system, i.e. reach return temperature as low as possible, while supply temperature was higher. In case of Næstved, we focused on reducing of supply temperature as much as possible even the return temperature is little bit higher, i.e. 33°C. It is a question for further work to find out if is for DHN more beneficial operate with lower supply temperature and higher flow rate or with lower return temperature and lower flow rate. The answer will be additionally defined by heat sources used in DHN. If reduction of the supply temperature is in focus SH system in Aarhus (case 2) can be operated on temperature level 50/30/20°C instead of 60/26/20°C to deliver the same power to the building.

- Temperature level needed for operation of SH system can be additionally decreased by enlargement of radiators or by further energetic renovation measures.

- The influence of higher flow rates on DHN for lower supply temperatures should be seen in consideration of type of in-house substation.

4.3 Evaluation of possible downsizing of the DHN based on reduced heat demand of the houses

Reduction of heat demand in existing building can be made by energy renovation, i.e. reduction of SH peak power demand and by change of DH substation from IHEU to DHSU. From peak power for DHW (which depends on type of DH substation) and peak power for SH a DHN is dimensioned. The influence of reduced SH peak power for individual buildings is important for dimensioning of whole DHN (beside branch pipes for substations with DHW priority, e.g. IHEU and DHSSU55), because simultaneity factor for SH is with increased number of connections asymptotically approaching 0.62% of peak load, while simultaneity factor of DHW decreasing much faster.

The biggest potential for downsizing of DHN is to perform energy renovation of the house, DHN and at the same time change DH substation from IHEU to type with buffer tank.

Table 17 shows the maximal peak load and maximal primary flow rates for different types of DH substations. It can be seen that in case of substations with priority of DHW heating (IHEU and DHSSU55) peak power for SH is lower than peak power for DHW heating and thus capacity/size of branch pipe (BP) is defined by peak flow for DHW heating and reduction of peak load for SH system hasn't influence. In both mentioned substations DHW priority can be used because tapping of DHW or/and fast charging takes short time and it is not resulting in decrease of thermal comfort while SH system is stopped. The influence of type of DH substation for dimensioning of DHN can be seen in the other project report [1], where simultaneity factors of IHEU and DHSU are discussed.

Table 17 – Maximal primary flow rates for different types of substations with supply temperature 50°C

substation type	max primary flow rate [L/min]*	peak load [kW]	*description*
IHEU - Lystrup	14.1	32.3	*IHEU Lystrup*
DHSU 120 L - Lystrup	1.66 + SH	2.8 + SH	*DHSU 120L- Lystrup*
DHSSU20**	2 + SH	4.5 + SH	*DHSSU 2L/min*
DHSSU55**	5.5	12.5	*DHSSU 5.5 L/min*
DHSU 200 L	0.2 + SH	0.5 + SH	*DHSU200L - 0.2 L/min*
***cooling 50/18°C**			
****DHSSU55 meaning charging flow rate is 5.5 L/min, DHSSU20 meaning charging flow rate 2L/min**			

Reduction of SH peak power is important for branch pipes supplying substations designed with lower charging flow rates, i.e. DHSU or DHSSU20. For those substations, charging can take long time and system cannot be operated with DHW priority and thus the peak load on BP is given by sum of DHW charging flow rate and peak load for SH.

<u>Example of possible downsizing of a branch pipes – case of house in Aarhus</u>

Recently the house in Aarhus is equipped with IHEU unit and thus 32.3kW peak power for DHW heating is needed. The branch pipe with inner diameter 16 mm is used (i.e. pipe almost corresponding to Aluflex 20/20/110). Renovation of the house from case 1 to case 3 (new low-energy windows) decreases peak flow rate for SH down to 70% of original value (from 2.75L/min to 1.93L/min) and allows operate SH system on temperature level 65/32/20°C instead of originally 70/40/20°C. In Table 18 possible dimensions of branch pipes for house renovated to two cases for two recently available types of DH in-house substations are shown.

In case of IHEU, reduction of peak power for SH has no direct influence on dimensioning of branch pipe if temperature of DH supplied from DHN remains the same, because pipe dimension is defined by flow needed for DHW heating. On the other hand, renovation measures taken on the house allows to operate SH system with reduced supply temperature and if temperature in DHN is decreased it has influence on dimensioning of branch pipe (and whole network), because with decreasing of supply temperature a flow/size of pipes needed for DHW heating is increasing. In Table 18 situations for three different supply temperatures are shown. It is 70°C, 65°C and 50°C for house renovated to case 1, 3 and for summer operation conditions respectively.

Table 18 - Possible downsizing of BP for Arhus model house, case 1 SH 70/40/20, case 2 SH 65/32/20°C for IHEU and DHSU-120L substations

DH substation	Case (house renovation)	branch pipe	max. flow for SH [L/min]	max. flow for DHW [L/min]*	total max. flow [L/min]	pressure drop [Pa/m]
DHSU – 120L	1	Aluflex 14/14/110	2.75	1.66***	4.41	1324
	3		1.93		3.59	910
	1	Aluflex 16/16/110	2.75	1.66	4.41	540
	3		1.93		3.59	373
	1	Aluflex 20/20/110	2.75	1.66	4.41	182
	3		1.93		3.59	126
IHEU	1	Aluflex 16/16/110	2.75	8.76	8.76	1899
	3		1.93	9.68	9.68	2286
	Summer**		0	14.1	14.1	4625
	1	Aluflex 20/20/110***	2.75	8.76	8.76	630
	3		1.93	9.68	9.68	756
	Summer**		0	14.1	14.1	1514
	1	recently used BP with inner diameter 16 mm	2.75	8.76	8.76	451
	3		1.93	9.68	9.68	550
	Summer**		0	14.1	14.1	1098
	1	Aluflex 26/26/125	2.75	8.76	8.76	154
	3		1.93	9.68	9.68	185
	Summer**		0	14.1	14.1	365
	1	Aluflex 32/32/125	2.75	8.76	8.76	43
	3		1.93	9.68	9.68	52
	Summer**		0	14.1	14.1	102

* calculated based on cooling 70/18 for case 1, 65/18°C for case 2 and 50/18°C for summer case

** for summer, supply temperature of 50dgc resulting in flow rate for DHW preparation 14.1L/min

*** constant value of 100L/hr

The conclusion is that the branch pipe for IHEU (with priority of DHW heating) should be dimensioned due to the flow rate needed for DHW preparation in period with lowest supply temperature.

For the existing building equipped with new low-energy IHEU, the max. pressure drop in BP will decrease from 1345 Pa/m (operation conditions for original IHEU was 60/31°C) to 1098 Pa/m for new operation temperature 50/18°C and thus existing BP can be used without problems.

If all houses in the area (houses around are the same type) will be renovated to case 3, capacity of pipes in DHN (excluding branch pipes for IHEU) needed for SH supply can be downsized by 30%.

If DH substation will be changed with DHSU-120L, whole DHN can be downsized even more than 30%, because peak power for DHW is decreased. The downsizing of DHN should be performed with consideration of simultaneity factors measured for DHSU in the other project report [1].

The influence of change from IHEU to DHSU and reduction of 30% in SH peak load on whole DHN is more complicated and is above level of this investigation.

Existing house renovated to case 3 can be equipped with DHSU 120L and supplied with branch pipe Aluflex 14/14/110 with design pressure gradient in branch pipe 1330Pa/m.

From comparison of pressure drops for IHEU and DHSU it can be seen, that for the house renovated to case 3 and DHN operated with the same max. pressure drop in the branch pipe for IHEU and DHSU, for IHEU branch pipe Aluflex 20/20/110 is needed and for DHSU Aluflex 14/14/110 is needed. Expected saved heat loss on branch pipe if Aluflex 14/14/110 is used is 30%.

4.4 Motivation of house owner for renovation measures

The level of renovation measures depends mainly on house owner. The house owners should be motivated to invest for the improvements leading in reduction of heat demand in the building. It can be supported by subsidy from DH company, e.g. by offer of loan with low level of interest or subsidy for renovation. The considerable effort should be also put to explain house owners that energy price will grow and now is the right time for renovation of their houses.

Another way how to explain to house owners the importance of renovation measures of their houses and transition to LTDH is that if the houses will not be renovated and DH should run on traditional temperatures, at the end of the day the customers will be the ones who will pay heat losses from network, because it will becomes part of the price of the heat.

It should be mentioned that the biggest energy saving will be reached if the renovation of DHN and connected building will be made in the same time.

4.5 Actions needed from district heating companies

From point of view of DHN, change to LTDH doesn’t need any immediate changes in DHN, only reduction of supply temperature. If DHN should be renovated because is at the end of its life-time, it should be considered if DHN should be sized down because of reduced heat demand caused by refurbishment of connected houses (if refurbishment was performed or is planned).

4.6 Scenarios for introduction of LTDH 50/25°C

DH network and connected buildings are in very close relation. If one of those is changed it immediately influences the other. To design LTDH for area of new low-energy buildings is not as big challenge as to make transformation of traditional DH systems to LTDH in areas with existing buildings.

Here we present four possible scenarios for introduction of LTDH to areas with existing buildings supplied originally by traditional DH.

Neither renovation of buildings, nor network
With successive decreasing of use of fossil fuels and introduction of renewable heat sources a pressure from heat plant owners to operate DH with reduced supply temperature because of better efficiency of renewable sources will increase. Keeping of traditional supply temperatures (if it will be possible) means lower efficiency of heat sources, higher heat loss from network both leading to worse economy. For customer this scenario will result in higher price of DH energy.

Renovation of buildings, no renovation of network
Reduction of heat demand of a building depends on the extent of building energy renovation. For DH network a decreased energy demand meaning possibility to decrease temperature of supply water or/and possibility to reduce diameter of DH pipes. Reducing of temperature can be done almost from day to day if all customers made similar extent of renovation. Reduced supply temperature means lower heat loss from DHN and thus better economy. The extent of possible reduction of supply temperature in DHN depends on buildings with need of highest supply temperature. Based on the number of such buildings a decision should be taken when and how much the supply temperature can be lowered.

Renovation of network, no renovation of buildings
This scenario is the worst possible. The renovation of DHN is usually caused by end of life-time of the DH pipes. Since in this case the houses are not energetically renovated, pipes of DHN should be dimensioned in the same sizes as old one. Only benefit from this renovation will be in reduced heat losses from DH pipes caused by improved insulation properties of the new DHN pipes.
If this scenario happens, DH company will not be willing to change again DH pipes in the near future (because of high investment and thus long pay-back time) even the houses will be renovated. Therefore DH company can be in some cases interested to give subsidy to house owners for house renovation and thus build network with lower diameter of pipes.

Contemporary renovation of buildings and network

The best scenario is to make renovation of buildings and right after renovation of DHN. In this case DH network can be downsized and thus heat loss from DHN will be maximally reduced.

4.7 Conclusions

For two investigated single-family houses built in 70s the supply temperature of DH can be reduced for considerable long part of the year (80% of traditional heating season with outdoor temperature above 0°C) to 50°C if basic renovation measures as change of the windows on existing buildings are taken and DH substations are changed.

For periods with outdoor temperature below 0°C (1258 hours), SH systems in both houses should be operated on temperatures higher than 50°C and thus increase of supply temperature from DHN is needed. This is however not seen as a problem, because the same principle is used in existing DHN. A question is if increase in supply temperature will be also possible in DHN supplied by 100% RES.

Supply temperature of DH can be for periods with outdoor temperature above 0°C in many cases reduced also without renovation measures, but then higher flow rate in SH system is needed and it results in increased return temperature from SH system. Higher return temperatures can lead in fines from DH companies because improper cooling is related to reduced efficiency of heat sources. Lower return temperature can be reached by enlarging of radiators in critical rooms, i.e. rooms defining level of supply temperature for SH system.

For periods with outdoor temperatures around 0°C flow rates needed for SH systems can be rather high because of lower temperature drop on radiators than for design conditions. It should be checked individually for each house if the flow needed for this period is not higher than flow needed for design conditions. If the flow is higher, the DHN and BP should designed be after that.

For introduction of LTDH with supply temperature 50°C in areas with existing buildings, recently used DH substation should be changed with LTDH substations. The reason is need of more efficient HEX and in case of existing substation with traditional DHW storage it is additionally caused by impossibility to store DHW bellow 55°C because of health safety (Legionella).

Thanks to the new IHEU with more efficient HEX for DHW preparation there is no need of change of branch pipes even the DHN will be operated on lowest temperature level 50/25°C instead of originally designed higher temperature as e.g. 60/30°C.

One string heating system is not suitable for LTDH concept, because cannot operate on decreased temperature level with proper cooling. Solution is to renovate SH system to two-string.

A possibility to down size DH networks for existing buildings depends on type of DH substation used in the building and level of renovation measures performed on the building

Energy renovation of existing buildings should be performed before or at the same time as renovation of DHN. House owners should be motivated by DH company to perform energy renovation of their house.

5 Studied optimization and applications of low-temperature district heating

In this chapter we investigate possibilities of reduction of peak power demand in buildings (single-family houses) and district heating (DH) installations in order to design an optimized low-temperature district heating system.

5.1 Equalization of heat demand for space heating and domestic hot water

One of the main challenges for Low-temperature District Heating (LTDH) and for district heating in general is to reduce heat losses from District Heating Network (DHN) as much as possible. The reasons are better economy and CO_2 emissions saved by reduction of heat loss. The heat losses are directly related to temperature of DH water, insulation properties of the DHN pipes and diameter of the pipes. The diameter of the DH pipes in DHN is designed based on the peak power demand and cooling ability of individual buildings with consideration of simultaneity factors and type of the DH substation installed in the buildings. Shortly, it can be said the lower the peak power for individual consumers, the smaller pipes in DHN and reduced heat loss.

A peak power for a building consists of power needed for space heating (SH) and for domestic hot water (DHW) preparation.

The reduction of peak power for SH and DHW can be made by:

- Energy saving measures on buildings resulting in reduced heat demand - e.g. more insulation, use mechanical ventilation system with efficient heat recovery
- Optimisation of SH system – by using of thermal capacity of buildings as a thermal storage and by improved control system
- Type of DH substation related to DHW heating - use of in-house buffer/storage tanks with big volume which will be charged continuously with low flow rate to average daily DHW demand

The reduction of peak power for SH and DHW preparation will bring following advantages:

- Network:
  - Possibility to reduce diameter of pipes in DHN and thus reduce heat losses from DHN
  - Reduced investment because DH network will be built from pipes with smaller diameter
- Customer
  - Lower price of heat because of reduced heat losses and initial investments to DHN
- Production side
  - Reduced maximal design power of heating plants i.e. lower investment cost
  - Continuous operation on designed power instead of intermittent operation
  - Reduced need of primary heat storage systems

For dimensioning of distribution pipes and transmission pipes simultaneity factor should be considered. The impact of the simultaneity factor on dimensioning of DHN is discussed in Delrapport 2 [1]. For dimensioning of Branch Pipes (BP), simultaneity factor is 1 and thus maximal peak power is considered.

Focused on single-family houses, we can distinguish between two concepts of LTDH substations: Instantaneous Heat Exchanger Unit (IHEU or in Danish GVV) and District Heating Storage Unit (DHSU or in Danish FVB). Both units are in detail described in Delrapport 2 [1].

- For IHEU design peak power is 32.3 kW defined by instantaneous preparation of DHW. In this case the peak power for SH in typical single-family houses is always lower than peak for DHW and because IHEU is operated with DHW priority, peak power for SH is not taken in account for dimensioning of branch pipe (BP). High design peak power results in need of BP with bigger inner diameter and thus higher heat loss. As a state-of-the-art solution, BP Aluflex 20/20/110 with inner diameter 15 mm and design pressure drop 1500 Pa/m is used in Lystrup, Denmark.

- For DHSU (low charging flow rate and big buffer tank), a BP with inner dimension reduced to 10 mm (Aluflex 14/14/110) is used. Dimension of BP is in this case based on sum of heat demand for SH for the building and charging flow rate for buffer tank for DHW. A peak power demand for DHW preparation is for DHSU a function of the volume of the buffer tank and charging flow rate. For example for low-energy house class 1 in Lystrup the peak power demand for SH is 2.8 kW and peak power demand for DHW is 3 kW, resulting in sum 5.8kW.

Calculated heat loss from BP for IHEU based on software of pipe's producer is due to bigger pipe diameter higher (Aluflex 20/20 instead of Aluflex 14/14), roughly 25% more than from BP in case of DHSU. If we consider also different operating principles of branch pipes for DHSU and IHEU, meaning than in first case there is no by-pass at all while in second case yes, the difference in heat loss from branch pipes is be higher. It was reported in Delrapport 2 [1] that heat loss from DHN is finally 30% higher in area with IHEU than in area of DHSU.

Moreover, in case of IHEU the branch pipe is fully used for designed flow rate only during tapping of DHW, which occurs several minutes per day and rest of the time is not fully used. For lowering the heat loss from a DHN is thus beneficial use solution with more constant heat load on DHN, i.e. pipes are used more often for designed flows as it is in case of DHSU concept.

Nevertheless the total energy demand that should be transported to individual users by DHN is still the same, but the profile of power demand is smoothed by averaging heat flow for SH and DHW.

5.2 Typical heating demands and peak loads for DHW and SH in new and existing buildings with traditional systems

To evaluate potential of peak power reduction we are reporting typical values for peak power and heat demand for DHW heating and SH in newly built and existing single-family houses.

5.2.1 SH in New houses

By new houses we meant buildings fulfilling at least Danish Building regulation BR06 [10]. As an example, single-family low-energy house class 1 with heated area 145m^2 reported by [11] is chosen. Total heating demand is reported in Table 19. The energy frame for energy class 1 is in this case 42.6 kWh/m^2. Although design operative temperature for all calculations is 20°C it is widely known that people usually prefers higher temperature which results in higher heat consumption and peak power than expected. The difference in heat demands caused by the increase of the desired operative temperature to 22°C can be also found in Table 19.

Table 19 – Total heating demand for "new house"

	Design indoor temperature 20°C		**Design indoor temperature 22°C**	
Heat demand	kWh/year	kWh/m²/year	kWh/year	kWh/m²/year
Domestic hot water*	2300	15.9	2300	15.9
Space heating	3028	20.9	4450	30.7
In total	5328	36.7	6750	46.5

* For calculation of DHW [11] uses value of 303L/m2.a heated from 10-55dgc, in BE06 value 250L/m2.a is used

It can be seen, that heat demand for space heating accounts for 56% and 66% of annual heat demand for operative temperature 20°C and 22°C respectively.

Table 20 – Power peak loads to SH systems and maximal flow rate from DH for SH in "new house"

	Energy demand for SH [MWh/year]	**Peak power for SH [kW]**	**Flow need for t_{out}=-21°C [L/min]****
radiators (t_{op}=20°C)	3028	3.15	1.78
radiators (t_{op}=22°C)	4450	3.4	1.9
traditional floor heating t_{op}=20°C)	3028	7.18*	4.03

* Feak power for floor heating occurs only 7 hours during whole year

**SH system is designed to operate for outside temperature -21°C with 50/25/20

Peak demand for space heating system of the model house equipped with radiators is 3.15 kW and 3.4kW for desired operative temperature 20°C and 22°C respectively. If the house is supplied with LTDH 50/25°C, mentioned peak power for SH represent flow rate of 1.78 and 1.9 L/min of DH water. The maximal flow rates for supply of SH system will be in real situation lower, because during period with very low outdoor temperature supply temperature of LTDH is expected to be increased. The mentioned values are taken as maximal possible values.

For case when the house is equipped with traditionally controlled floor heating system with on/off control, the peak power is 7.18 kW corresponding to 4.03 L/min of DH water with cooling 50/25°C.

5.2.2 SH in Existing buildings from 70s

In Table 21 and Table 22 the heat demand and peak power for SH are shown for two typical houses built in 70s in Aarhus and Næstved. Both houses are equipped with SH system with radiators. The results are based on simulation in BSim software. Both houses and whole investigation is in detail described in chapter 4 and appendix 3 and 4. It is expected that some of the houses has been already renovated, so we defined three cases with different level of basic renovation. Case 1 is case of not renovated house, i.e. the condition as it was built in 70s. Case 2 is original house with changed glazing in windows and case 3 is house with completely new low-energy windows (frame + glazing).

Case	**Dimensioned heat loss (-12°C) [W]**	**Heat demand [MWh/year]**	**Het demand pr. area [kWh/m²]**	**Peak power for SH [kW]**	**flow rate from DHN for max peak load [L/min]**	**Temperature needed in radiators for:**
						T_{out}=-21°C
1	12 583	25.9	181	11.8	4.21	80/40/20
2	7 437*	19.5	136	9.7	3.28	75/33/20
3	4 108	17.2	120	8.3	3.18	70/33/20
4**	4 108	17.2	120	8.3	3.79	64/33/20

*House with new glazing has still big heat loss by infiltration because of leaky windows frames

**House with new low-energy windows (case 3) + new low-temperature radiators

Table 21 – Energy demand for space heating, maximal power and temperature needed for space heating system in typical house from 70s in Aarhus, area 120m²

Case	**windows properties**	**Energy demand for SH [MWh/year]**	**Flow need for t_{out}=-21°C [L/min]**	**Peak power for SH [kW]**	**Temperature needed in radiators for:**
					T_{out}=-21°C
1	U-value: 2.5 W/m^{2}K g-value: 0.43	10.49	2.75	5,8	70/40/20
2	U- value: 1.4 W/m^{2}K g- value: 0.43	8.3	2.36	5,0	65/35/20
3	U- value: 0.9 W/m²K g- value: 0.35	7.55	1.93	4,5	65/32/20

It can be seen, that by changing the windows (renovation from case 1 to case 3) the reduction in heat demand is 28% and 33% for case of Arhus and Næstved model house respectively. The reduction in peak power demand for space heating is lower, 22% and 29% for Arhus and Næstved model house.

Table 22 – Data for a typical Danish house from the 70s. The reference house is located in Naestved and has an area of 143 m²

Case	Dimensioned heat loss (-12°C) [W]	Heat demand [MWh/year]	Het demand pr. area [kWh/m²]	Peak power for SH [kW]	flow rate from DHN for max peak load [L/min]	Temperature needed in radiators for:
						T_{out}=-21°C
1	12 583	25.9	181	11.8	4.21	80/40/20
2	7 437*	19.5	136	9.7	3.28	75/33/20
3	4 108	17.2	120	8.3	3.18	70/33/20
4**	4 108	17.2	120	8.3	3.79	64/33/20

*House with new glazing has still big heat loss by infiltration because of leaky windows frames

**House with new low-energy windows (case 3) + new low-temperature radiators

5.2.3 DHW – heat demand and peak power

First we should distinguish between DHW profile used for design of equipment (e.g. branch pipes, DH in-house substation, feeding pipes in houses) and DHW profile used for calculations of annual DHW consumption.

Designing of DHW system:

For designing of DHW system the maximal needed flow rates and frequency of individual tappings are defined in DS439 [8].

The peak power demand for DHW on secondary side is for single-family house without bath tub defined by power needed for simultaneous supply of shower and kitchen sink, i.e. 32.3 kW and is independent on type of DH substation.

Contrary to that, the peak power demand from DHN depends on the type of DH substation (see Table 23). For IHEU, design peak power is whole 100% of power needed on secondary side, i.e. 32.3 kW. For cooling of DH water from 50/18°C it corresponds to flow 14.1L/min. For DHSU maximal primary peak power for DHW heating depends on size of the buffer tank which is related to charging flow rate. The bigger the buffer tank is the lower charging flow rate, meaning lower power from DHN, is needed. As an example, DHSU used in Lystrup with size of buffer tank 120L has design flow rate for DHW preparation 3kW, i.e. 100 L/hr (1,66 L/min) for cooling 50/25°C.

Table 23 – maximal primary flow rates for different types of substations with supply temperature 50°C

substation type	max primary flow rate [L/min]*	peak load from DHN [kW]
IHEU – Lystrup	14.1	32.3
DHSU 120 L -Lystrup	1.66 + SH	3 + SH
DHSU 200 L -referring to [12]	0.2 + SH	0.5 + SH

*Cooling 50/18°C

The difference in maximal peak power for IHEU and DHSU results in different dimensions of pipes in DHN because with increasing peak power, supplied volume of DH water is higher and to keep the same pressure gradient in network, pipes should be enlarged.

Tapping profile:
The tapping profiles typical for one-person household, average EU single family and family taking two baths daily can be found in EN 15316-3-1:2007 - Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 3-1 [17] in Annex A. Due to our opinion, these tapping profiles can be used for calculation of annual energy demand for DHW, but for dimensioning of pipes and substations are too low.

Annual DHW consumption:
The tapping profile from DS439 [8] can’t be used for calculation of annual DHW consumption just by multiplication of 24-hours draw off by 365 days, because it will lead to unrealistically big numbers.

The yearly DHW consumption in single-family houses is a function of house area and is defined by BR06 as 250L/m^2 year of warm water heated from 10°C to 55°C. Examples of heat demand for three model houses used in this part of report are reported in Table 24. Definition of heat demand of DHW is being recently discussed, but it is not in scope of this report. Anyway for dimensioning of DHN it is important peak power demand and not annual heat demand.

Table 24 – DHW consumption and energy needed for DHW heating

	Heated house area [m²]	DHW demand [$L_{(10\text{-}55°C)}/m^2\cdot a$]	Total heat demand for DHW [kWh/a]	Heat demand for DHW [kWh/a·m²]	DHW consumption per day [L]
Arhus	120	0.25	1568	13.1	82
Næstved	143	0.25	1868	13.1	98
Lemvig*	145	0.25	1894	13.1	99
Lemvig**	145	0.303	2296	15.8	120

* due to BE06 [10]

** due to [11]

5.2.4 Total peak power for single family houses

Based on the data presented for three model houses, the Naestved house is taken as an example of a house with highest peak power for SH. The peak power needed from DHN for SH system in case of not renovated house (case 1) is 11.8kW. For the same house with new windows (case 3) the peak power for SH is 8.3 kW. The design power for connection of building to DHN will depends on type of DH substation and it can be:

- IHEU – peak power is defined by design power for DHW heating, i.e. 32.3 kW, space heating is not included to peak power because IHEU is operated with priority of DHW.

Possible improvement for this concept is use branch pipe with smaller dimension to reduce heat loss from DHN, but it will be paid by increased pressure drop in DHN connected with higher pumping costs. Reducing diameter of pipes in DHN is limited by max. available pressure gradient in the network. The pressure gradient for transporting 32.3 kW (14.1L/min with cooling 50/18°C) in BP Aluflex 14/14/110 and Aluflex 20/20/110 will be 11600Pa/m and 1500Pa/m respectively. This concept is discussed in detail in chapter 5.4.5.

- DHSU – peak power depends on volume of buffer tank and charging flow rate. For traditional concept with high-volume buffer tank the priority for DHW preparation cannot be used and thus peak power will be defined as the sum of DHW and SH peak power. For Næstved house renovated to case 3 (peak power 8.3kW) equipped with buffer tank with size 120L (DHSU used in Lystrup - 2.8 kW for DHW), the design power for connection will be 11.1 kW, which is 66% less than in case of IHEU (32.3kW). The pressure gradient for transporting 11.1 kW in BP is 1700Pa/m and 230Pa/m for Aluflex 14/14/110 and Aluflex 20/20/110 respectively. For calculation of pressure drop, operation of SH system on temperature level 64/33/20 was used.

For case of low-energy house, with peak power for SH 3.4 kW (referring to [11], design operative temperature 22°C), the difference between solution with IHEU, i.e. peak power 32.3 kW and solution with 120L DHSU, i.e. 6.2 kW is bigger and accounts for reduction of 80%. In case of use branch pipe Aluflex 14/14/110 with inner diameter 10 mm, pressure gradient for max. peak power will be around 900 Pa/m. For Aluflex 20/20/110 with inner diameter 15 mm the pressure gradient will decrease to 120Pa/m. For calculation of the maximum pressure drop, operation of SH system on 50/25/20°C was used.

It can be concluded that using of DHSU lead for our example of low-energy house in reduction of peak power by 80% in comparison with IHEU.

5.3 Possibilities for reduction of peak load for SH

In previous chapter a peak power for SH systems in three model houses were discussed. In this chapter a possibilities for reduction of peak load for SH systems are studied and reported.

A heat demand and peak power for SH in a building depends on the building itself (year of construction is tightly related to heat loss through envelope and ventilation system, on internal heat gains, size and orientation of windows and thermal mass, etc.) and on the heating system and its control.

5.3.1 Influence of building

Heat loss through envelope
Heat loss through envelope is for new highly insulated buildings reduced considerably in comparison with existing buildings.

Heat loss through infiltration and ventilation system

The heat loss by infiltration and venting contributes considerably to heat demand for SH in existing buildings equipped with old leaky windows. Once the windows frames are changed, the building increase its tightness and thus heat loss by infiltration is reduced considerably. But fresh air should be supplied anyway. In such cases, installation of mechanical ventilation system with heat recover will be very expensive. The solution is to install venting valves. The difference between old leaky windows and venting valves is in possibility to control supplied flow rate and thus reduce heat loss by ventilation. For new buildings built with good envelope and mechanical ventilation system with highly efficient heat recovery the heat loss by ventilation/infiltration is very low.

Size of windows and buildings orientation

For new buildings, heat demand and peak power can be reduced by proper size and orientations of the windows

Use of thermal mass

For new buildings, heat load and peak power can be reduced by proper use of thermal mass [13]. Nevertheless for existing buildings changes in thermal mass are not possible.

For low-energy buildings built from light construction possible use of thermal mass is reduced. On the other hand, in case of traditional buildings with bigger thermal mass use of thermal mass is limited by higher heat losses.

5.3.2 Influence of SH systems and its control

Type of space heating system and its control strategy has a big impact on peak power load for SH. For space heating systems supplied by LTDH a reduction of peak power and proper cooling of heating water is very much in focus.

Reduction of peak power for floor heating supplied by LTDH

Reduction of peak power for a floor heating system can be achieved by continuous supply of heating water with mean water temperature reduced to lowest possible level, i.e. low supply temperature with high flow rate instead of short-time pulse operation with high peak power.

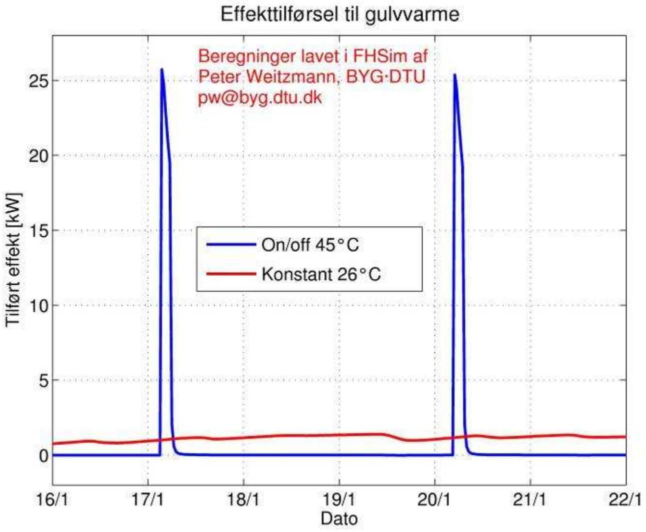


Figure 14 – Comparison of peak power for floor heating system for on/off-control system and for constant flow control system.

Comparison of both mentioned control strategies for floor heating system in building with quite high heat loss is shown in Figure 14. Many traditional floor heating systems are usually controlled by on/off-control system supplying water with high supply temperature. This means that periods with no heat supply are followed by periods with high power supply. The on/off-solution is not a problem for traditional high temperature heat sources of energy, e.g. boilers operated with natural gas, where it is not so important to operate on low temperature level, with good cooling and without peak loads, but with introduction of low-temperature sources it becomes important.

If we talk about floor heating system supplied with LTDH, on/off-control results in higher peak flow rates than necessary and then DHN should be dimensioned after that with higher capacity of DH pipes, resulting in higher heat loss from DHN.

The reason why on/off-control concept is recently widely used is no need of low return temperature for traditional heat sources and also higher price of control valves with adjustable flow needed for this control strategy. Alternative to the valves with adjustable flow is simple flow limiter on primary side and proper hydraulic balance of the system. Recently some manufactures of floor heating systems already implemented this system.

Using of continual supply of heating water leads to more uniform distribution of temperature in the floor and thus lower risk of overheating. Moreover by decreasing supply temperature from 45°C to 30°C, up to 6% of energy can be saved [14].

When applying continual supply control to floor heating system, desired is to supply SH system with minimal continual power but always provide desired thermal comfort. By following these two constraints the optimal flow rate can be found. The investigation of continual control strategy for floor heating is reported in following text.

Reduction of peak power for radiators supplied by LTDH

Reduction of peak power in case of radiators is not really possible by improved control strategy as it is in case of floor heating. Since recently used panel radiators has very limited thermal accumulation, reduction in peak power for radiators can be to some very limited extent done only by use of thermal mass of the building for accumulation of heat. In case of newly built houses this is however problem, because new houses are made from light constructions with low thermal mass. Contrary to that, older existing buildings were built with higher thermal mass but transmission heat loss is higher and thus advantage of higher thermal mass is lost. The possibilities in reduction of peak power for radiators by use of thermal mass are expected very low, because for accumulation of heat only first several centimetres of inner construction is used and thus reduction of peak power will have immediately influence on thermal comfort in the room.

Beside reduction of peak load [kW] for SH system, reduction of corresponding supply flow rate from DHN [L/min] is not less important for dimensioning of DHN. A SH system with radiators is more related to second mentioned. The supply flow rate from DHN is defined by cooling ability of SH system. If temperature of heating water returning from SH system is lowered, supply flow rate is reduced as well. In SH system with radiators a proper cooling is realized by proper hydraulic balance and use of radiators with enough large surface. But even if a SH system is equipped with radiators with large surface an area for heat transfer is smaller than in case of floor heating system. It results in higher return temperature from SH system with radiators and thus higher flow rate needed for the same power transmitted by radiators than for floor heating.

When designing radiators operating on low temperature level in low-energy buildings, size of radiators is quite small and it allows without problems increase heating surface of the radiators and thus reaches desired proper cooling of the heating water. Another situation can occur for existing buildings with higher heat demand. In this case needed size of radiators can be bigger than available space and thus proper cooling can be reduced.

For designing of radiators, it shouldn’t be forgotten, that DH system is usually during extremely cold periods operated with higher temperatures. This solution is recently used in traditional DH systems however it should be investigated if this concept is optimal for LTDH.

5.3.3 Numerical simulation

BSim simulations were performed to evaluate potential for peak load reduction for SH in new and existing buildings for different space heating system and its control. In newly built buildings investigations were carried out for radiators as well as for floor heating system, in existing building only radiators were investigated.

Calculation model for floor heating

Originally it was intended to develop own calculation model for detailed simulation of buildings supplied by floor heating, but meanwhile the new version of software BSim including detail modelling of floor heating was introduced, so we decided to use it.

As a starting point, the model of the reference house created in software BSim by P.K.Olsen [11] has been used. It is one storey detached house with heated area of 145 m². The house is low-energy class 1 (LEC 1) according to BR08 [4], where energy demand = 35+1100/A kWh/m² per year (A = heated area).

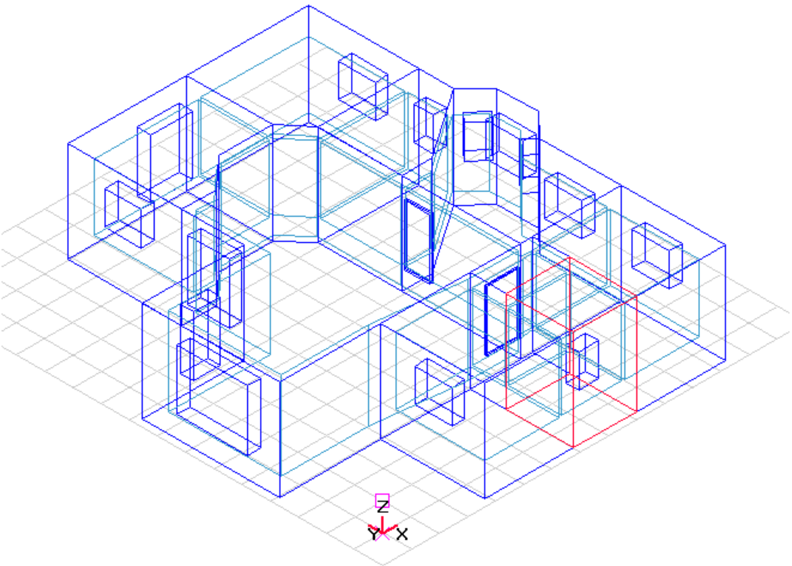


Figure 15 – Model of low-energy house class 1 in BSim software

The model of the house was modified by adding floor heating module for investigation if the thermal comfort can be reached when flow rate for floor heating supplied from LTDH is restricted to 2 L/min (120 L/hour) with design cooling 55/25°C. It is done in order to evaluate possibility of minimizing the size of the pipes in district heating network and therefore minimize the heat loss from DHN. The assumption is that flow rate 2L/min will be sufficient to keep operative temperature of 20°C inside the house when outside temperature is close to 0°C. For extremes with lower outside temperatures the assumption is that the temperature of water in district heating network will be increased. For normal situations the temperature of supply water in DH network is assumed to be 55°C and temperature of return water to be 25°C. This means that power available for space heating in normal situation is

$$Q = V.\rho.c.\Delta T = (2/1000/60*1000*4159*30) = 4{,}18 \text{ kW}$$

Floor composition

The module of hydronic floor heating was additionally implemented to the model of the reference house in program BSim. The original composition of the floor was left without any changes and the pipes of the floor heating circuit were embedded. The composition of the floor is shown in Table 25.

Table 25 - Composition of the floor for model house with floor heating

Layer of material	Thickness [m]
Wood	0,014
Anhydrite	0,03
Concrete	0,1
EPS	0,4

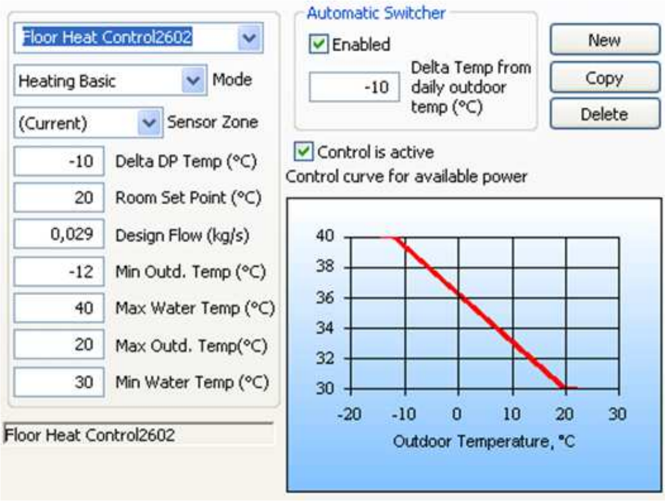
Sand	0,2

The floor heating pipes were embedded between the layers of anhydrite and concrete. The pipes with external diameter of 16 mm and wall thickness of 2.2 mm were used. The thermal conductivity of the pipes used was 0.42 W/mK. Pipes were placed in the distance of 0.275m from each other.

Modelling of Control system for floor heating in BSim

1, On/off control system

The control system of the floor heating in program BSim works similarly as regular control system used in practice. This means on/off-control principle. When there is a need for heating in the space the control system set the control valve to open position and the water is coming to the floor heating loop. The flow rate of water to floor heating loop is fixed in BSim. The energy input to the floor is further adjusted by changing the temperature of supply water. The temperature of the supply water to the floor heating loop is changing according to outside temperature. Temperature curve is then created. The input panel of hydronic floor heating from program BSim can be seen in Figure 16.



Floor Heat Control2602

Heating Basic — Mode

(Current) — Sensor Zone

-10 Delta DP Temp (°C)

20 Room Set Point (°C)

0,029 Design Flow (kg/s)

-12 Min Outd. Temp (°C)

40 Max Water Temp (°C)

20 Max Outd. Temp(°C)

30 Min Water Temp (°C)

Automatic Switcher

☑ Enabled

-10 Delta Temp from daily outdoor temp (°C)

☑ Control is active

Control curve for available power

Floor Heat Control2602

Figure 16 – BSim – input box for floor heating control

2, Control system for continuous supply of heating water, i.e. system with floor limiter

The way how to assure continuous supply of floor heating system is to use is to use flow limiter limiting maximal flow to floor heating system. Because in the program BSim it is possible only to use an on/off-control system, the minimal flow rate for continuous supply strategy should be found by fixing desired supply temperature and step-by-step decreasing of maximal flow rate until operative temperature decrease below desired value.

5.3.4 Peak power for space heating systems WITHOUT FLOW LIMITER

In this section, results of BSim simulations of peak power for space heating systems without flow limitation is reported for three different buildings described previous in the text. Results therefore report the situation of how it is usually done in practice.

Floor heating

Low-energy class 1 house with floor heating

The yearly curve of power demand and operative temperature for an example of LEC 1 with floor heating controlled by on/off-strategy is shown in Figure 17. As already mentioned, our aim is to operate floor heating system with maximal available power 4.18 kW. The maximum peak power for floor heating goes up to 7.8 kW (blue curve) nevertheless power higher than 4.18kW is experienced only 7 hours during the whole year. The average operative temperature in the house is during those 7 hours kept between 17.9-20.1 °C (red curve). Seven hours during whole year is very negligible number and it will have no significant effect on comfort of the people living in the house. Furthermore the situation can be improved by increased supply temperature of DH as it is usually done today. For the rest of the time, the peak power demand is lower than 4.18kW.

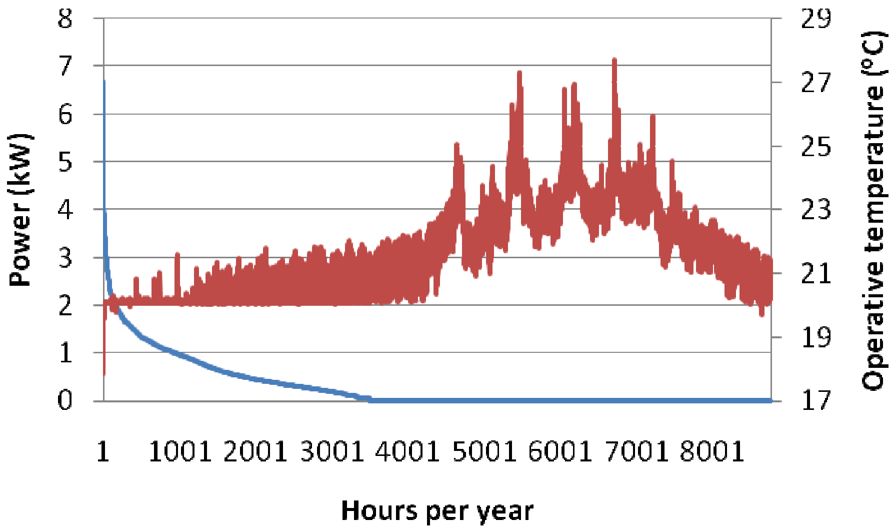


Figure 17 - Power demand for floor heating and operative temperature in low-energy house class 1

Input data to model

The maximum temperature of the water supplied to the floor heating was set to 40°C. The flow rate of water in floor heating was set to 3 L/min in each loop. This is the maximum value for flow rate usually used in the loop of floor heating in practice. This flow rate should ensure that the temperature is evenly distributed over the surface of the floor. On the other hand, it should be mentioned that with increasing flow rate a pressure drop increases as well and it results in higher consumption of energy used for pump. The design reference year (DRY) was used for calculations in program BSim. Thermal properties of the constructions in the house used during calculations can be seen in Table 26.

Table 26: U-values for constructions used in LEC 1 house and in Danish typical house from 70s

Thermal properties LEC 1	
Construction	**U-value** [W/m^{2}K]
Floor	0.08
Roof	0.08
External wall	0.26
Window	0.9

Thermal properties typical for 70s	
Construction	**U-value** [W/m^{2}K]
Floor	0.31
Roof	0.33
External wall	0.66
Window	1.7

From Figure 17 it can be seen that when the heating is active the temperatures grows sometimes to the value of 21°C. This is rather normal situation, since there is always some fluctuation and it is not possible to reach exact set point. The highest temperatures occur in periods when heating system is not in operation. Those are probably caused by sun radiation and other heat gains during the summer periods.

Typical house built in 70s with floor heating

The peak power for floor heating in the example of LEC 1 was very small. In order to compare influence of the heat loss on the maximal peak power to floor heating, the properties of constructions of the model LEC1 house were changed to values typically used in 70s (see Table 26).

1) Without ventilation system (i.e. without heat recovery unit)

The house was modelled without ventilation system but with infiltration of 0.5h-1. The heat demand and operative temperature for space heating in imaginary house with constructions from 70s is shown in Figure 18. It can be seen that in comparison with building built in accordance with low-energy class I standard the peak power and energy consumption are in this case generally higher throughout the whole year. The peak power delivery is about 6 kW. The necessary power for floor heating is higher than available power (4,18kW) in 2400 hours. From Figure 18 can be observed that the operative temperature in the house is below the set-point of 20°C rather often. It is obvious that designed floor heating system is not sufficient and not able to deliver required amount of energy to the house. As a solution the heating system working in higher temperature should be installed (for example radiators working in temperatures about 70°C.

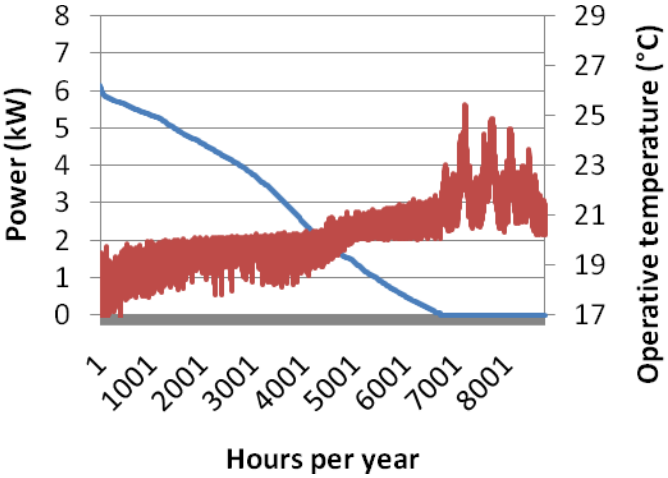


Figure 18 - 70's- floor heating when heat recovery from ventilation is 0%

2) Ventilation system with heat recovery with efficiency of 90%

Reasonably improved situation is in the house when the ventilation system with heat recovery is installed. The indoor operative temperature doesn't drop below required 20°C as often as in previous case. The situation is significantly improved when heating set point is set to 20,5°C instead of 20°C. The explanation for this phenomenon is that response for the need of heat is rather slow in case of floor heating and since the heat losses through the walls, roof, floor and windows are much higher than in case of low-energy class house, therefore the temperature drops dramatically. In other words, the reaction time of floor heating compare to the heat losses is too large. The flow rate for simulation was limited to 3 L/min per loop and input temperature 45°C. The peak power is about 5.5 kW.

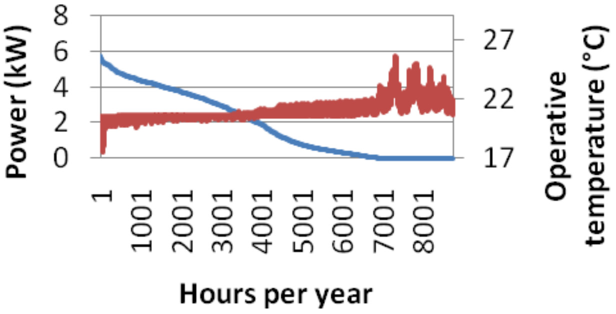


Figure 19 - Heat demand for floor heating for house with U-value of constructions typically used in 70's with heat ventilation system with heat recovery with efficiency of 90% (set point 20,5°C)

Radiators

Low energy class I house- With radiators

In order to investigate what would be the difference in peak power for space heating system if the radiators are used instead of floor heating the model of LEC 1 in BSim was changed accordingly. Set point temperature for heating was set to 20.5°C. In Figure 20 results for heat demand for LEC1 house heated by floor heating and radiators are compared. It can be noticed that the shape of the curve expressing the power delivery for radiators (blue curve) is a bit different than in case when floor heating was used. The peak power delivery is about 2.13 kW. It can be seen that in case of heating system with radiators the amount of hours when heating is active is larger but lower power. This is caused by thermal mass being activated in case of floor heating. Therefore the power input to the floor is larger but being delivered in shorter period of time, so final energy consumption is the same for both systems. In case of the operative temperature (red curve), the fluctuations of the temperature are a bit larger for radiators than in case of floor heating. This is however a bit unexpected since one could expect that the room temperature would be more stable in case when radiators are being used. This assumption is made since the time constant of radiators is much shorter than in case of floor heating (there is no thermal mass causing the long time constant in case of radiators).

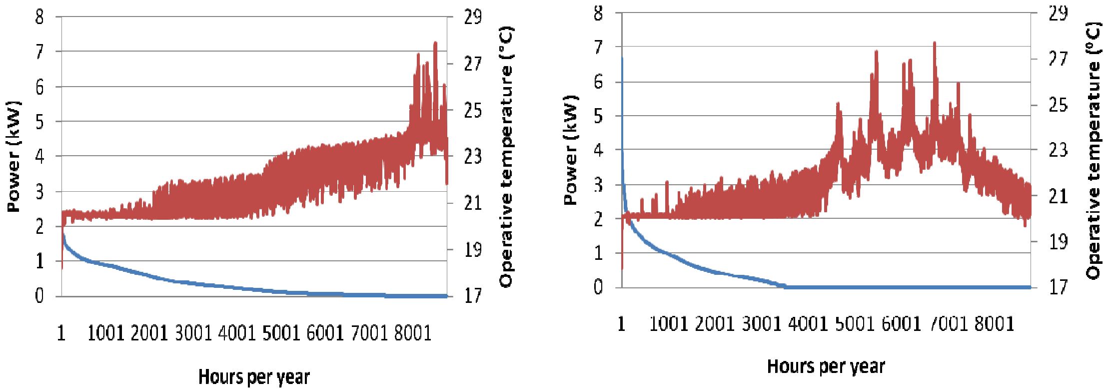


Figure 20 - Heat demand for low energy house class 1; LEFT - radiators, RIGHT – floor heating

Existing buildings from 70's with radiators

The maximal power for SH with radiators in existing buildings from 70s with different levels of renovation is shortly reported in chapter 5.2.2 and more in detail in appendix 3 and 4.

5.3.5 Peak power for space heating WITH FLOW LIMITER

Floor heating

The hypothesis is that if the heating water will be supplied continuously with lower temperature, the peaks in energy delivery would become lower. This solution is suitable for floor heating, because of activation of thermal mass in the floor and therefore minimizing of the fluctuation of energy being delivered to the room. This part investigates if the floor heating system can be operated with smooth continuous delivery of energy instead of intermittent, high power peaks operation.

The investigation was made for low-energy house described in chapter 5.3.3. The closer investigation was carried out only for one room (living room) for the situation when the outside temperature was around 0°C. For periods with lower outside temperatures the assumption is that the temperature of water in district heating network will be increased. For design situations the temperature of supply water in DH network is assumed to be 55°C and temperature of return water to be 25°C. This means that power available for space heating in normal situation is 4.18 kW. The comparison between two control principles, i.e. on/off and continuous supply with flow limiter is reported bellow.

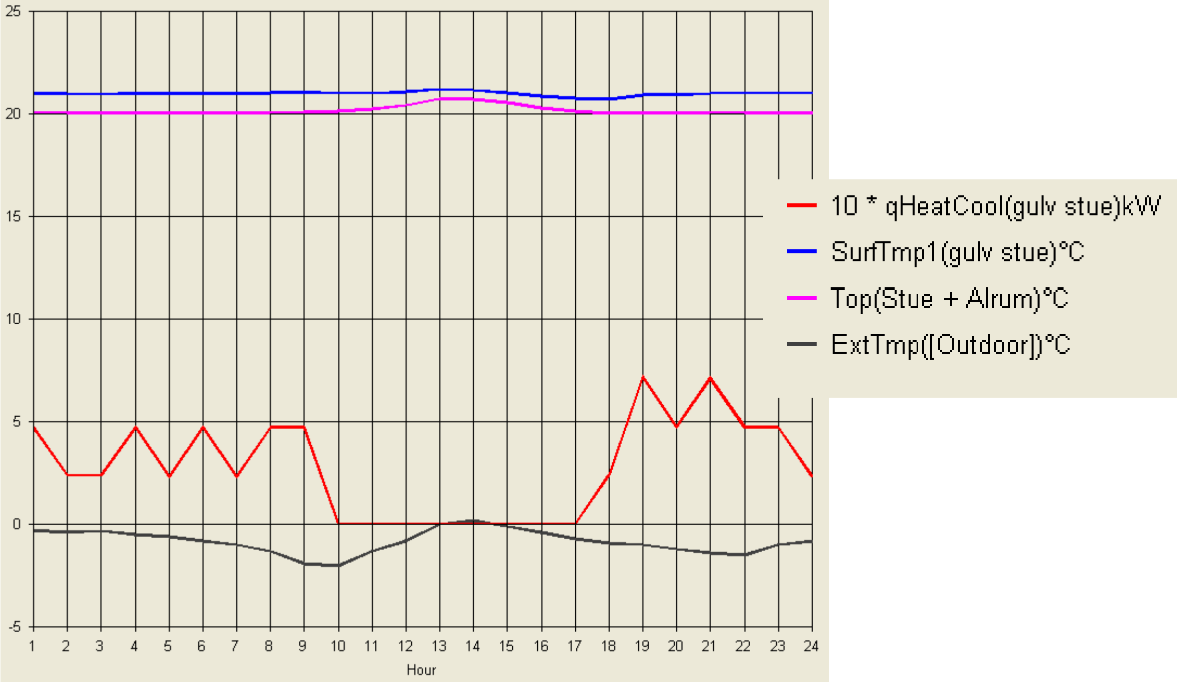


Figure 21 - Fluctuating of power delivery when no limiter is being used

On/off-control principle

The result of the simulations for one room with outside temperature being close to 0°C and maximal supply temperature to the floor heating restricted to the 40°C can be seen in Figure 21. It can be observed that the floor heating control system is switching the input of power rather often. As a result the peak power is 0.7 kW in investigated day. The flow rate in floor heating loop was 3L/min.

Continuous supply - Flow limiter

In comparison to the situation without flow limiter, Figure 22 shows the situation where the maximum inlet temperature was set to 40°C and flow rate to 0,65 L/min. Flow rate of 0.65 L/min was chosen by continual reducing of flow rate from initial 3L/min to the lowest flow rate not causing drop of operative temperature bellow 20°C. As a result, more smooth and stable delivery of energy to the floor heating is achieved. In this way, the peak flow of the energy input was lowered to 0.4 kW which is about 40% less than in case without flow limiter scenario. This implies that if the power supply to the floor heating is smoothed, the restrictions in the flow rate of DH water in branch pipe can be realized.

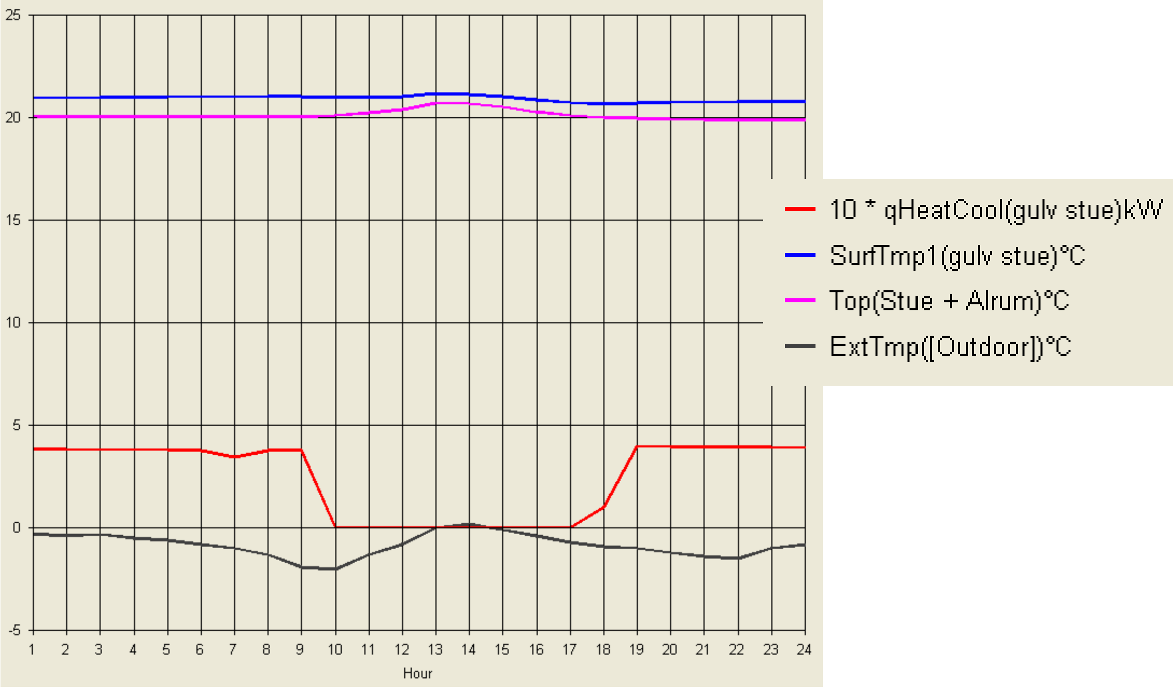


Figure 22 - Power delivery to the floor heating when flow limiter is being used

Radiators

For SH system with properly dimensioned and hydraulically balanced radiators, the proper cooling is achieved and radiators cover actual heat losses without any surplus power. It is thanks to low thermal mass and thus short time constant of the radiators. The limitation of radiators power bellow needed power will result in drop in operative temperature and thus decreased thermal comfort. The potential in peak demand reduction for radiators with slight reduction in thermal comfort is very low and thus it is not interesting for LTDH concept.

5.3.6 Conclusion on reduction of peak load for SH

The limitation of peak power for SH system is important for reduction of pipe diameters in DHN.

Dimension of branch pipe depends on type of DH substation used for heating of DHW. It is discussed in next chapter.

For buildings equipped with continuously operated, properly designed radiators there is no significant reduction of peak power because of low thermal mass of radiators and limited ability of constructions to accumulate heat. Reduction in peak power for radiators leads to reduction in desired operative temperature. The benefit of such a measure doesn't bring any significant potential in reduction of peak load for space heating.

For low-energy houses equipped with floor heating system, peak power for space heating can be reduced by use of control system assuring continuous supply of heating water to the floor heating loop instead of on/off-control up to 40%. Benefit for LTDH is in possible reduction in diameter of DH pipes in DHN and in better cooling of water returning to DHN which is reached caused by reduced mean water temperature in floor heating. Possibility in reduction of peak power for buildings with higher heat demand is expected higher, but those buildings are usually not equipped with floor heating system and weren't investigated in detail in this report.

It is suggested to continue in investigation of influence of thermal mass, e.g. floor composition, on reduction of peak power to the floor heating system

5.4 Possibilities for reduction of peak load for DHW

Reduction of peak power for preparation of DHW is possible by use of in-house substation with buffer tank for DH water, i.e. DHSU concept. In this case, maximal peak power for DHW is reduced substantially in comparison with IHEU (32.3 kW). In case of DHSU maximal peak power for DHW preparation is defined by charging flow rate of the buffer tank. The charging flow rate is a function of size and stand-by temperature of the buffer tank and design pattern of DHW use during a day. As an example, we refer to DHSU used in Lystrup with buffer tank 120L and charging flow rate 100 L/hr (1.66 L/min, approx. 3kW).

DHSU concept is very beneficial for DHN by reducing peak loads and thus reducing dimensions of all pipes in DHN network, but in comparison with IHEU it has also some disadvantages:

- **Heat loss from buffer tank**: the benefit of reduced peak power and heat loss from DHN (due to reduced diameter of pipes) is paid back by higher heat loss from a substation. A comparison of heat loss from DHSU and IHEU including branch pipes is reported in the other project report [1] in chapter 4.2 and 6.1.3.

- **Space requirements**: a presence of buffer tank makes substation bigger. The need of space is usually not a problem for single-family houses, where DHSU can be installed e.g. in technical room. But it can happen e.g. in case of renovated houses the space for DHSU is not available and the same problem occurs in case of apartment buildings

- **Higher initial cost**: since DHSU contains in comparison with IHEU buffer tank, circulation pump and digital controller, the price of DHSU is higher

- **Worse cooling of DH water**: once the buffer tank is fully charged a heat loss to ambient environment decreasing temperature of stored water and water should be sometimes reheated. As a consequence DH water with temperature higher than 25°C is sent back to the DHN during reheating and few last moments of charging period. This problem can be to some extent solved by use of not properly cooled water for serially connected floor heating system

- **Risk of run out of DHW**: considering DHSU from Lystrup show case (the only realized type of DHSU concept) flow limiter on primary side allows max. charging flow rate for DHW 1.66L/min (100L/hr) and it can happens that user runs out of DHW if the DHW draw off pattern used for design of DHSU is exceeded

- **Use maximal available capacity (pressure gradient) in BP:** In recently realized case of DHSU (volume 120L), flow capacity and pressure gradient available in BP is not used on 100%. A branch pipe with smallest available diameter is recently Aluflex 14/14/110 with inner pipe diameter 10 mm. For the design conditions of DHSU used for Lystrup C2 type house, max. flow rate (SH + DHW) is 5,8kW, i.e. 2.92 L/min (cooling 55/25). It corresponds to pressure drop of 626 Pa/m. It is however lower than design pressure drop 1500 Pa/m used for branch pipes of IHEU.

On the other hand, advantage of DHSU is lower heat loss from DHN, more constant heat load on DHN and higher comfort for DHW delivery, i.e. lower waiting time and no need of by-pass.

To exploit advantages of DHSU and reduce disadvantages, new type of low-temperature district heating substation with reduced buffer tank volume is investigated.

5.4.1 Definition of the new concept

Based on the mentioned "disadvantages" of traditional DHSU a new concept should fulfil following requirements:

- Reduced peak power for DHN, i.e. equalized heat load
- Low price
- Low space requirements
- High level of DHW comfort for users
- Low stand-by heat loss
- Proper cooling of DH water
- Use of all available flow capacity and pressure drop in DHN

5.4.2 DHW tapping profile - requirements for DHW

The developed substation should fulfil draw-off profile for DHW defined by Danish standard DS439 [8]. The draw of profile is enforced twice a day from 6:00 to 18:00 and from 18:00 to 6:00. The DHW consumption for each 12 hours is 368L and consists of:

- 4 showers with need of 42L of 40°C warm DHW (flow rate 8.4L/min)
- 2 kitchen washes with need of 15L of 45°C warm DHW (flow rate 6L/min), repeated 4 times in 12 hours

- 4 hand washes with need of 10L DHW with temperature 40°C (flow rate 3.36L/min), repeated 2 times in 12 hours.

In Figure 23 graphical interpretation of maximal taping profile for DS439 is shown.

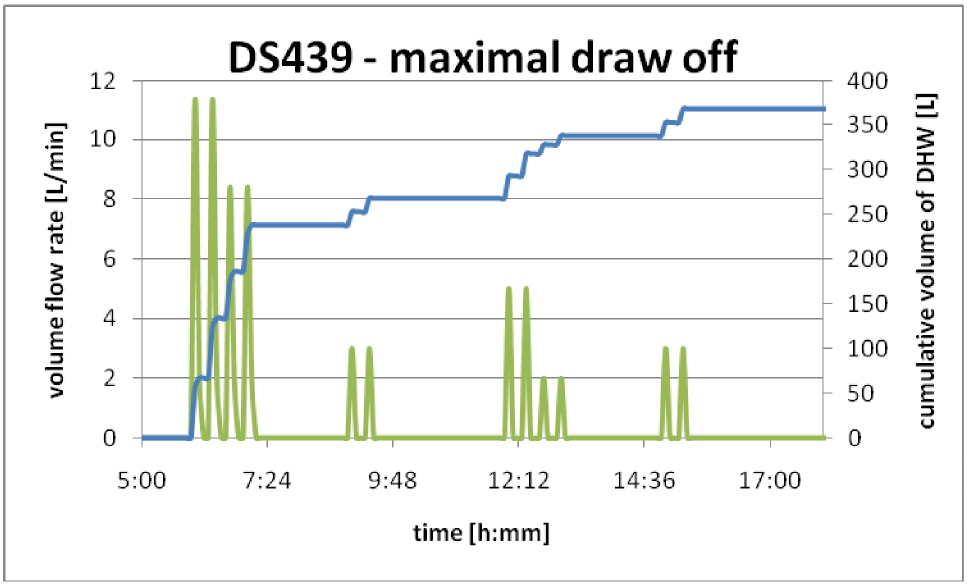


Figure 23 - "Maximal" draw off profile defined by DS439 [8], i.e. individual DHW tapings are repeated with highest possible frequency

In our work we slightly differ from the DS439 standard in temperature of DHW for kitchen sink. As it was done in work of [12] we defined temperature of DHW for kitchen tap 40° instead of 45°C. This assumption is made in order to make preliminary calculations less complicated

5.4.3 Optimization of DHSU

On first sight, DHSU with a large buffer tank and very low charging flow rate smoothing DHW demand through whole day looks like the best solution. It was shown that this solution is very beneficial for DHN, but the problems with proper cooling of DH water can occur during idling period and for cases with actual DHW demand lower than designed [12]. On the other hand, if DHW tapping pattern is higher than designed, user will run out of DHW because buffer tank will be full of cold water and small charging flow rate cannot supply DHW by instantaneous principle. It will take quite long time, depending on charging flow rate, to recharge storage to take e.g. shower. The other disadvantages related to concept with big storage tank and low charging flow rate were already mentioned in the text above.

The optimal solution for DH substation equipped with buffer tank is a compromise between charging flow rate and size of the buffer tank. Our aim is to reduce size of the buffer tank as much as possible while still keeping possibility of averaging heat demand from DHN and use maximal possible pressure gradient in DHN. At the same time the aim is to use BP with smallest available diameter, i.e. Aluflex 14/14/110 with inner diameter 10 mm to assure lowest possible heat loss from BP. In Table 27 the pressure gradients for BP Aluflex 14/14/110 are presented for different flow rates.

The value of maximal allowed pressure gradient (and thus maximal flow rate) in DHN has influence on design of new substation (charging flow rate → size of buffer tank). As a baseline we use design pressure drop for BP supplying IHEU in Lystrup, i.e. 1500 Pa/m. For BP Aluflex 14/14/110 it corresponds to primary flow rate 4.7 L/min. For case when the maximal allowable pressure drop can be increased to 2000 Pa/m, we can supply 5.5 L/min.

Table 27 – Branch pipe Aluflex 14/14/110 with inner diameter 10 mm – pressure drop for different flow rates, roughness of pipe 0.02 mm

Pressure drop for maximal flow, roughness of pipe 0.02 mm				pipe length [m] 10+10	
max pressure drop [Pa/m]	pipe diameter [mm]	max flow [L/h]	max flow [L/min]	total press drop S+R [bar]	velocity [m/s]
100	10	60	1	0.02	0.21
500	10	156	2.6	0.1	0.55
1000	10	228	3.8	0.2	0.81
1500*	10	282	4.7	0.3	1.00
2000	10	330	5.5	0.4	1.17
11633	10	11633	14.1	2.33	2.99

*the pressure loss 1500 Pa/m is designed pressure gradient for BP for IHEU in Lystrup

Since maximal allowed pressure drop depends on design of DHN, we defined two possible solutions for DHSU optimization:

1) Optimized DHSU with low pressure gradient in BP

- Size of buffer tank is lower than in case of traditional DHSU, but pressure drop in BP is still low
- Based on work of Fan [12] an example can be a 60L buffer tank with charging flow rate of 2L/min

2) Optimized DHSU with high pressure gradient in BP:

- Volume of buffer tank is reduced as much as possible while charging flow rate is increased to maximum, concept resulting in considerable pressure gradients in BP

A different philosophy was used for original design of traditional DHSU as described by Fan in [12]:

- Big volume of buffer tank and minimal charging flow rate
- Big benefit for reducing of peak power and averaging of flow rate in DHN

As an example we refer to DHSU with 200L buffer tank originally designed for Lystrup as described in [12]. For this case, charging flow rate for DHW was low as 0.2L/min, but the unit wasn't finally used because space requirements were too high and thus unit with 120L is used instead.

Operation principle

Proposed concept is named “District Heating Small Storage Unit” (DHSSU). Sketch of DHSSU is shown in Figure 24. It is in fact DHSU equipped with smaller buffer tank with some modifications related to reduced volume of the buffer tank.

DHSSU under normal conditions operates in 3 modes which are in detailed described below:

1 - DHW tapping:

District heating water is stored in the buffer tank on primary side. When DHW is needed, control valve of heat exchanger (HEX) asks primary side for supply of DH water. DH water is primary supplied from DH network. When demand of DH water is higher than maximal designed flow rate from DHN water from buffer tank is supplied as well. In this feature DHSSU differs from traditional DHSU, where HEX is supplied only from buffer tank as long as it is possible. Circulation pump runs always when there is need for DHW. During tapping, three situations can occur:

a) HEX is supplied by max. flow from DHN and the rest of needed DH water from the buffer tank

This situation occurs when HEX needs more flow than can be delivered from DHN. DHN supplies max. available flow (path A-D on Figure 24) and rest of the needed flow is supplied from buffer tank (path C-D). Both flows are mixed in intersection of path B-C-D and supplied to HEX. After passing the HEX the same amount of district heating water, as was supplied from DHN, is sent back to DHN and rest is send back to lower part of buffer tank. The circulation pump is used to deliver DH water stored in buffer tank to HEX and back to the buffer tank.

b) HEX needs less water than is max. flow rate from DHN

In this situation, DH water is taken only from DHN and directly sent to HEX and then back to DHN.

c) HEX is supplied only from DHN because buffer tank is empty

It can happen that buffer tank is full of cold water because user used more DHW than was designed. In this case flow of cold water from buffer tank is stopped and HEX is supplied only with maximal flow rate from DHN.

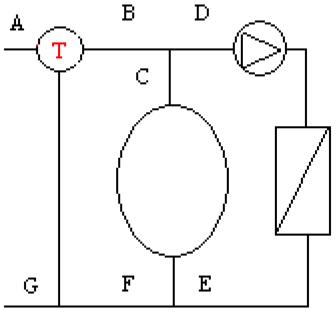


Figure 24 – Operation principle of DHSSU

2 - Charging

Charging is active only when there is no DHW tapping on secondary side. The buffer tank is charged from DHN with maximal flow rate (path A-B-C to supply warm DH water and path

F-G to sent cold water back to DHN). Circulation pump doesn't run, charging is driven by network differential pressure. When buffer tank is completely charged with warm DH water, charging is stopped.

3 - Reheating - covering the stand-by heat loss:
When DHSSU idling for some time (no use of DHW) district heating water stored in the buffer tank cools down by heat loss to ambient environment. Charging starts when water in buffer tank cools below the stand-by temperature. Since DH water in branch pipe is expected to cool down faster than water stored in the buffer tank, cooled water from branch pipe will enter the buffer tank on the beginning of reheating and unnecessarily cool down stored water. The amount of cooled water entering the buffer tank depends on the diameter and length of the branch pipe, heat demand of neighbouring DH customers at that time and presence of by-pass solution in the network/in-house substations. The problem with DH water cooled in BP can occur only outside of heating season, because during heating season BP is kept warm by heat demand of houses. Cooling of water in BP Aluflex 20/20/110 during idling for different ground temperatures is discussed in the other project report [1] in chapter 4.4.2. It can be seen that outside of heating season, water standing in BP will be cooled from 50°C to 25°C after 150 minutes of idling (no flow in BP). For Aluflex 14/14/110 will be time needed to cool down water standing in BP slightly longer. Evaluation of risk of charging with cold water is discussed in one of following chapters.

Calculation of volume of buffer tank and charging times
We made preliminary calculations investigating optimal size of the buffer tank needed for different charging flow rates and stand-by temperatures of buffer tank.

Assumptions for calculations
Since this work is made only as preliminary investigation, several simplifications are assumed. If the preliminary results prove that concept is promising, more advanced calculations will be done. The assumptions for calculations are:

- DHW draw off profile due to DS439 [8] – the maximal possible draw off profile (realistic for peak demand of DHW, but not realistic in everyday use) is considered in order to be on safe side cf. [12].
- HEX has 100% efficiency, i.e. all energy from primary side is transferred to secondary side and no heat loss to ambient during DHW preparation
- Temperature of DHW for kitchen sink is assumed 40°C instead of 45°C defined by DS439 [8]
- There is no mixing in the storage tank, neither during charging, neither during draw off
- Calculation of heat loss from the tank is made in simple way cf. [12]

Inputs for an Excel calculation:
- Maximal supplied flow rate from DHN and temperature of supplied DH water
- Desired temperature and flow rate of DHW defined by DHW draw off profile
- Stand-by temperature of the buffer tank
- Temperature of cold potable water (T_{21})

Results of the Excel calculation:

- Size of the buffer tank
- Maximum time needed to recharge the buffer tank, influenced by DHW draw off profile

Results of calculations

Results of calculations investigating size of buffer tank needed to fulfil DHW tapping profile for different charging flow rates are reported in Table 28. Moreover theoretical recharging time (time needed for completely recharge of cold buffer tank if there is no tapping) and critical charging time (time needed for complete recharge if design tapping profile is performed with individual shortest possible pause between tapping) is shown.

Table 28 – Size of buffer tanks for different max. flow rates from DHN, temperature of cold potable water is 10°C

pressure drop in 10 mm pipe is 320 Pa/m

stand-by temperature in buffer [dgc]	size of the tank [L]	DHN charging flow [L/min]	theoretic time of charging [min]	max. time of charging [min]	max flow from buffer tank [L/min]	T21[dgc]
49	46.4	2	23	91	9.1	10
47	48.9	2	24	92	9.5	10
44	53.2	2	27	94	10.4	10
40	60.3	2	30	98	11.8	10

pressure drop in 10 mm pipe is 1000 Pa/m

stand-by temperature in buffer [dgc]	size of the tank [L]	DHN charging flow [L/min]	theoretic time of charging [min]	max. time of charging [min]	max flow from buffer tank [L/min]	T21[dgc]
49	24.6	3.8	6.5	7	7.2	10
47	25.9	3.8	6.8	7	7.6	10
44	28.2	3.8	7.4	8	8.3	10
40	32.0	3.8	8.4	9	9.4	10

pressure drop in 10 mm pipe is 1500 Pa/m

stand-by temperature in buffer [dgc]	size of the tank [L]	DHN charging flow [L/min]	theoretic time of charging [min]	max. time of charging [min]	max flow from buffer tank [L/min]	T21[dgc]
49	20.0	4.7	4.3	5	6.3	10
47	21.1	4.7	4.5	5	6.7	10
44	23.0	4.7	4.9	5	7.3	10
40	26.1	4.7	5.5	6	8.2	10

pressure drop in 10 mm pipe is 2000 Pa/m

stand-by temperature in buffer [dgc]	size of the tank [L]	DHN charging flow [L/min]	theoretic time of charging [min]	max. time of charging [min]	max flow from buffer tank [L/min]	T21[dgc]
49	16.0	5.5	3	3	5.5	10
47	16.9	5.5	3	3	5.8	10
44	18.4	5.5	3	3	6.3	10
40	20.8	5.5	4	4	7.2	10

It can be seen, that needed size of the buffer tank is lower for increasing charging flow rates and increasing stand-by temperatures.

The advantage of highest charging flow rate 5.5L/min is that even the buffer tank is empty user can take shower almost with nominal flow rate, because flow of DHW for primary flow rate of 5.5 L/min with temperature 50°C will be 6.3 L/min (considering thermal efficiency of HEX of 86%) of DHW with 40°C heated up from 10°C cold water. The flow rate for showering 6.3L/min instead of 8.4L/min is seen as acceptable. An alternative is to wait one minute and accumulate enough DH to provide shower with design value of flow rate.

The advantage of lower stand-by temperature is lower stand by-heat loss from buffer tank (because of decreased temperature difference between ambient temperature and stand-by temperature) and longer periods between reheating of buffer tank. Anyway stand-by temperature 40°C doesn't mean that buffer tank is charged with 40°C, but only a set-point temperature for reheating of buffer tank. Buffer tank is in this case charged with DH water with 50°C and reheating starts when temperature in buffer tank falls below 40°C.

Evaluation of DHW tap delay & cold charging for solutions without by-pass
In this part an influence of cold branch pipe (BP without by-pass) on DHW tap delay and charging with cold water for DHSSU concept is evaluated.

In general DH substations are today equipped with thermostatic-proportional controller for DHW heating. The controller on beginning of each tapping opens primary flow through HEX on maximal possible flow for period until DHW set-point temperature is reached. This control philosophy can be a problem for DHSSU concept operated without by-pass or with by-pass kept on temperature lower than DHW set-point temperature because during this period additional water from buffer tank is needed. As a consequence surplus DH water taken from the buffer can be missed later during tapping. Moreover during period before DHW set-point temperature is reached, DH water is improperly cooled. We will explain it on the example.

Let's assume that desired flow of DHW is Q_{DHW}=8.4 L/min, DH water in buffer tank is stored on 44°C and set point for DHW is 40°C. Water in BP was cooled to 20°C, and max. flow rate from DHN is 5,5L/min. Mixing of 5.5L/min of 20°C supplied from BP with theoretically needed 2.9 L/min of 44°C water (8.4-5.5) from buffer tank will result in 8.4L/min with temperature 28°C. Since temperature of mixed water is 28°C and it is lower than DHW set-point temperature 40°C it will cause that DHW controller asks for more water from buffer tank (flow from BP is already on maximum). It will cause surplus flow from buffer tank and thus faster emptying. The additional flow from buffer tank will stop when BP will start supply DH water warm enough that temperature of mixed water reach DHW set-point temperature.

In Table 29 the need of surplus water from buffer tank for case without by-pass is shown for four different DH flow rates and three different DHW flow rates. The DHW flow rates are basin 3.36 L/min, shower 8.4 L/min and shower + kitchen sink 14.6 L/min. The assumptions for calculation are T_{DHW} for kitchen and other tapping points is 40°C, branch pipe is full of DH water with temperature 20°C, there is no influence of thermal capacity of BP and all water coming to BP from street pipe is with temperature 49.5°C.

Table 29 – Volume of surplus water from buffer tank during first moments of tapping if water from BP is bellow DHW set-point (in this case 20°C), max flow rate though HEX is 14.1 L/min, stand-by temperature in buffer tank is 44°C, temperature of "fresh" DH water is 49.5°C, DHW set-point temperature is 40°C

flow from DHN [L/min]	DHW flow rate [L/min]	Flow rate needed from buffer [L/min] if DH=49.5dgc	Volume of DHw [L] from BT for tapping	transportation Time in BP [sec]	flow rate [L/min] from BT when controller fully open	volume of water [L] taken from buffer during transportation time	surplus water taken from buffer [L]	temperature supplied to HEX during transport delay [dgc]
2.6	3.36	-0.06	-0.14	18.1	11.5	3.5	3.5	39.6
3.8	3.36	-1.45	-3.63	12.4	10.3	2.1	2.1	37.5
4.7	3.36	-2.50	-6.24	10.0	9.4	1.6	1.6	36.0
5.5	3.36	-3.43	-8.56	8.6	8.6	1.2	1.2	34.6
2.6	8.4	4.39	21.96	18.1	11.5	3.5	2.14	39.6
3.8	8.4	3.00	14.99	12.4	10.3	2.1	1.51	37.5
4.7	8.4	1.95	9.76	10.0	9.4	1.6	1.24	36.0
5.5	8.4	1.02	5.11	8.6	8.6	1.2	1.09	34.6
2.6	14.4	9.69	48.43	18.1	11.5	3.5	0.55	39.5
3.8	14.4	8.29	41.46	12.4	10.3	2.1	0.42	37.5
4.7	14.4	7.25	36.23	10.0	9.4	1.6	0.36	36.0
5.5	14.4	6.32	31.58	8.6	8.6	1.2	0.33	34.6

The need of surplus volume of DH water from buffer tank is increasing for cases with lower charging flow rate and with decreasing flow rate of DHW. On the other hand temperature of water mixed from DH water and water from buffer tank decreasing with increasing charging flow rate. It is partly compensated by reduced period of DHW flow with temperature lower than set-point temperature (shorter transportation delay) but e.g. for charging flow rate 5.5 L/min HEX is supplied with 34.6°C primary water for first 8.6 sec which leads to considerable tapping delay on DHW side to produce DHW with 40°C.

In general, it can be seen that surplus volume taken from the buffer tank is for our assumptions relatively small. For example for DHSSU with charging flow rate of 2L/min and buffer tank volume 53L surplus water for hands washing is 3.5L, which is around 7% of overall buffer tank volume. Waiting times for DHW with desired temperature are for small charging flow rates considerable longer than for bigger flow rates, but temperature of DHW is during waiting period higher. It can be seen that for case of charging flow rate 2L/min temperature of mixed flow 39.6°C almost fulfilling desired value of 40°C.

The question is if our assumption that distribution pipes are kept continuously on temperature 49.5°C even outside of heating season is valid also in areas without by-pass in DHN or in-house substations. Once DH water in distribution pipes (not in BP) is cooled below $T_{DHWsetpoint}$, the waiting time for DH water with desired temperature can be considerably longer, leading in unsatisfactory temperature of DHW (below $T_{DHWsetpoint}$) and in some extreme cases whole volume of warm water stored in buffer tank can be lost.

A similar calculation can be done for situation with by-pass operation. The amount of surplus water from buffer tank will be lower because BP will start supply DH water with proper temperature faster. Moreover temperature of DHW will be in first moments after tapping starts higher than in case without by-pass.

The waiting time for DHW and volume of surplus DH water needed from buffer tank can be vanished by continuous keeping of BP on temperature higher than DHW set-point temperature. Requirement is to operate such a system in energy efficient way, i.e. use by-passed DH water and not send it back to DHN not properly cooled. A solution can be concept of "comfort bathroom" which is described below.

Measures for reduction of DHW tap delay & cold charging

Preventing of buffer tank charging with cold water and reduction of waiting time for DHW with desired temperature almost on level of traditional DHW storage tanks can be assured by:

<u>Comfort bathroom concept for keeping BP warm</u>

The concept is based on traditional by-pass solution for in-house DH substations, but DH water circulating through by-pass is used for all-year-around heating of floor in bathroom. DH water with low flow rate is circulating continuously in BP and thus keeping BP on desired temperature. The difference with traditional by-pass is in use of by-passed DH water in floor heating system in bathroom instead of by-passing not properly cooled DH water back to DHN. The flow rates needed to keep BP on desired temperature and power available for tempering of bathroom (cooling of water to 25°C) are shown in Table 30. The temperature of ground was chosen 8°C, but results for temperature of ground 14°C (summer conditions, not presented in this report) differs insignificantly. The results are based on calculations codes in the software Matlab. The codes are developed by Dalla Rosa [15].

In connection with DHSSU, two solutions are available:

- By-pass set-point temperature is lower than stand-by temperature of buffer tank. By-passed water is in this case sent directly into floor heating loop to temper floor bathroom or to towel rail radiator. In this case the buffer tank is reheated only when temperature of stored water drops bellow stand-by temperature.

  Example: DHW set-point temperature 40°C, buffer tank kept minimally on 44°C, by-pass flow on 35°C.

- By-pass set-point temperature is higher than stand-by temperature of buffer tank. Flow rate in BP is kept high enough to deliver DH water with slightly higher temperature than temperature of DH water stored in buffer tank. DH water with higher temperature is supplied to top part of buffer tank with very slow momentum. It results in “piston flow” and thus the coldest water on the bottom of buffer tank is replaced. In this way the heat loss from buffer tank is covered. The water from bottom part of buffer tank is sent to SH loop. This concept was already described in [16].

Example: DHW set point temperature 40°C, buffer stand-by temperature 44°C, by-pass 45°C

Table 30 – Flow and power available for bathroom floor heating (cooling of return water to 25°C) for BP 10 mm, 10 m long, price for 1MWh was 520 DKK (district heating price from Københavns Energy, January 2010)

Tg=8°C - transient period, 10 mm BP								
Desired by-pass temperature in the substation [°C]	35.0	40.0	42.0	45.0	46.0	47. 0	48.0	49.0
Needed flow [L/min]	0.023	0.037	0.048	0.080	0.102	0.138	0.209	0.423
Needed flow [L/hr]	1.38	2.22	2.88	4.8	6.12	8.28	12.54	25.38
available "comfort heat" [W] (cooling to 25°C)	16	39	57	112	149	211	335	707
energy [W/K$_{ofcooling}$]	2	3	3	6	7	10	15	29
heat loss from BP	24.0	26.0	26.8	27.9	28.3	28.7	29.0	29.4
flow [L/day]	33	54	69	116	147	198	301	609
flow [L/month]	996	1619	2084	3473	4399	5941	9024	18270
price customer [DKR/month]	6.5	15.9	23.1	45.4	60.3	85.3	135.5	286.3
price DH company [DKR/month]	9.7	15.8	20.4	34.0	43.1	58.2	88.4	179

The desired stand-by temperature of buffer tank has an influence on size of the buffer tank, heat loss* to ambient and power available for “comfort bathroom” floor heating. The lower stand-by temperature (stand-by temperature = temperature when charging starts) is set, the longer is period between individual recharging during idling. Preliminarily, we suggest stand-by temperature 44°C as the optimum between power available for comfort bathroom floor heating, DHW comfort for user and running costs. From Table 30 can be seen, that keeping BP on temperature 45°C gives 112W available for covering heat loss of buffer tank and supply of floor heating in bathroom. This setup will costs user 270 DKK for 6 months outside a heating season. Economy and possible influence on overheating in low-energy houses is discussed further in the next chapter.

**The heat loss from buffer tank is defined by average stand-by temperature, overall heat transfer coefficient from the buffer tank and by ambient temperature. The procedure of calculation is shown in [12]. Nevertheless we should mention that this simple calculation can differ from real heat loss, because calculation doesn’t consider some aspects increasing heat loss, e.g. influence of connection of feeding pipes.*

On demand by-pass

An alternative solution preventing cold charging and reducing waiting time for DHW can be "on demand" by-pass. The principle of operation is in preventing DH water with temperature lower than desired to enter buffer tank or HEX by "on demand" by-passing back to DHN. The by-passing back to DHN works only during:

- Beginning of reheating – DH water cooled by standing in BP is sent by by-pass back to DHN (see Figure 24, path A-G, in point T a three-way valve is installed) until DH water with temperature higher than stand-by temperature is available at the inlet to substation,
- Beginning of DHW tapping – DH water is by-passed back to DHN (see Figure 24, path A-G) until desired temperature is reached, then water is sent to HEX. Until DH water with desired temperature is available all needed primary water is supplied from the buffer tank. The flow to HEX is forced by circulation pump.

The advantage of "on demand by-pass" concept is to provide the same DHW comfort as in case of traditional storage tank concept and no need of by-passes for individual customers, DH water standing in BP can without any problems cool down. The disadvantage is in more sophisticated, electronically controlled control system and need of bigger buffer tank (surplus water for beginning of DHW tapping). Moreover it is a question if for areas equipped with DHSSU with "on demand" by-pass a by-pass on street level will be necessary to keep distribution network warm during summer periods with low heat demand.

Economy and influence of "comfort bathroom" concept on overheating in a low-energy house

The two important questions should be answered in connection with comfort bathroom concept:

1) Risk of overheating in low-energy houses
2) How much costs operation

We will explain both on an example:
DHSSU with 30L buffer tank needs to be kept on stand-by temperature 44°C. Based on the calculation it results in heat loss of 11W (very simplified solution, in reality higher value is expected). This 11 W can be covered by by-pass flow rate of 0.08 L/min cooled from 45°C to 43°C. It results in 100 W available (cooling from 43°C to 25°C) for floor heating (see Table 30).

We modelled both heat loads (DHSSU-11W and floor heating 100W) by simplified approach in BSim software to find out if there is a risk of overheating in LEC1 house.

Area of the bathroom in the model house is around 7m^2. The floor temperature is assumed 27°C, overall heat transfer coefficient is 9.2 W/m^2.K and t_{AIR} is 24°C. It gives 3K temperature difference, resulting in available heat flux 27.6W/m^2. By dividing 100/27.6 we obtain 3.6 m^2, which is minimal area of floor needed for transfer desired heating power. This simple calculation shows possibility to transfer desired power from floor heating to bathroom.

Results from BSim simulation investigating increase in operative temperature in bathroom and in laundry (room where substation is placed) after floor heating (100W) and substation (11W) was implemented are shown in Figure 25.

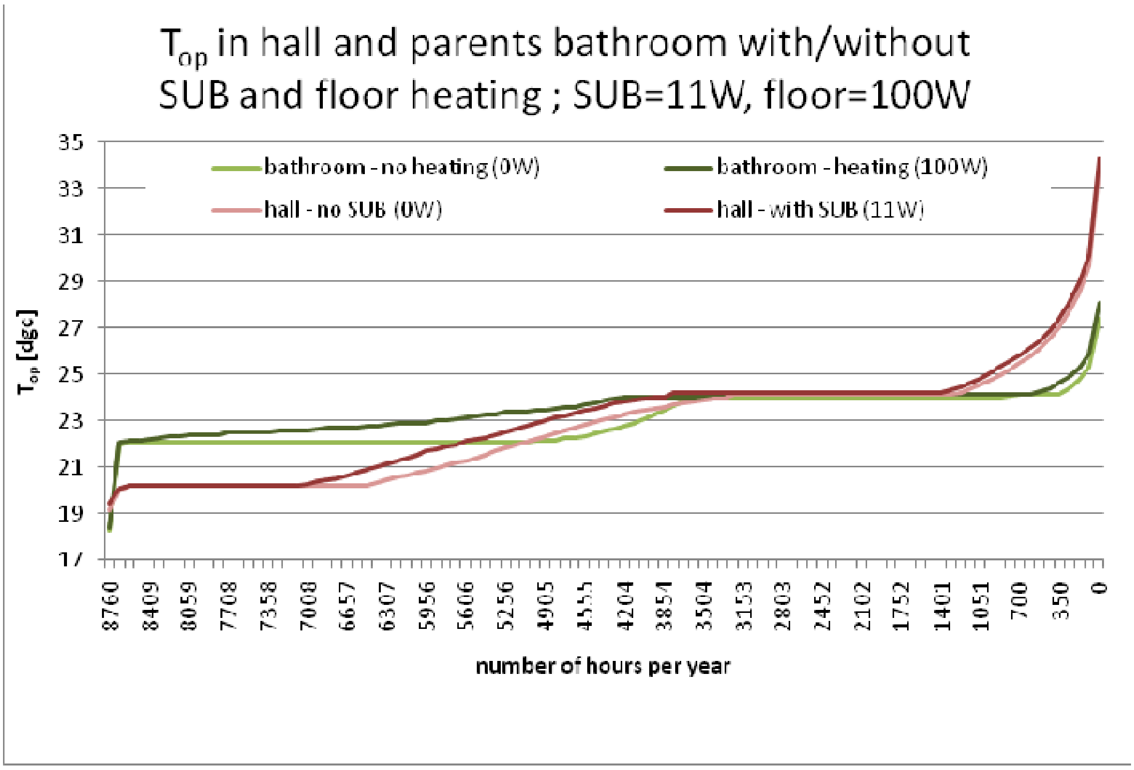


Figure 25 – Increase in operative temperature in bathroom and in laundry after substation (11W) and floor heating (100W) was implemented

It can be seen that there is small increase in operative temperature, but nothing critical. In case of bathroom, an increase in operative temperature to 24°C can be moreover seen as beneficial, because people prefers higher temperatures in bathroom. We should emphasize that warm floor in the bathrooms is very often used for increase of thermal comfort and in many cases electrical floor heating with higher price is used. From Figure 25 it can be also seen that for small amount hours during a year DH water supplying floor heating will not be cooled properly because air temperature in the bathroom will be higher than 27°C and auto regulation phenomena of floor heating will happen. This situation is estimated to occur for considerably small number of hours during whole year.

The running cost of by-pass solution for customer was for this case calculated to 270 DKK per year. The price accounts heat for 6 months outside a heating season and average cooling of DH water from 45°C to 25°C.

With use of comfort bathroom concept user will gain:

- High comfort for DHW – no waiting time, because substation is still ready to use
- Pleasant feeling in bathroom - no cold floor
- No bad environmental conscience from using of electric floor heating just for comfort

- Proper cooling of DH water – which can lead to discount from price of heat because of proper cooling

Keeping 45°C degrees on inlet to substation was chosen as an optimal solution. If higher temperature is desired, the by-pass flow-rate will be higher, resulting in higher cost and heat available from floor heating. In low-energy houses it can cause overheating, but in existing building with higher heat demand it will not be probably a problem.

This solution is also beneficial for DH company. Outside of heating season, mainly during summer holidays, problems with not enough circulation in DHN are experienced, resulting in reduced temperature of DH water before reaches customer. The solution for such a situation is usually increased supply temperature or use by-pass at critical points of DHN. The comfort bathroom solution will keep water in DHN network in continual movement and it will ensure proper cooling and thus it is more beneficial than traditional solutions.

5.4.4 Challenges in DHSSU development

The work on DHSSU development presented above is just a concept. For basic calculations many simplifying assumptions were made. The next step will be to consider all real physical phenomena.

Real efficiency of heat exchanger
The heat exchanger efficiency for design conditions is estimated to be around 88% on hot side, i.e. size of buffer tank should be increased by approximately 14%.

Heat conduction in the wall of buffer tank

- For traditional big storage tanks a problem with destruction of stratification by heat conduction in the steel wall is experienced. The steel wall has higher value of thermal conduction that water and causing natural convection and thus mixing of water in storage tank.
- This problem is probably not critical for DHSSU concept because water in storage tank is most of the time warm. The bottom part of buffer tank is cold only during tapping of DHW, but the buffer tank is quickly recharged (depends on charging flow rate)
- If it will be found that the heat conduction in the wall is a problem, it is suggested to investigate if it is possible to make buffer tank from material with lower thermal conductivity, most probably some plastic material. The problem with strength of material can be solved e.g. by implementation of metal cage from outside.

Thermal bridges from pipes connection
By supply/exhaust pipe connected to buffer tank considerably big amount of heat is lost because the pipes work as thermal bridges. Recently used concept of DHSU has supply and exhaust pipe on opposite sides of buffer tank. The better solution will be to install both pipes in one end. Both solutions are shown in Figure 26. By use of PEX pipes heat loss by conduction will be decreased considerably in comparison with steel pipes. The investigation should be made if it is possible. To find out proper solution is supported by fact that importance of heat loss through connection pipes grows with decreasing volume of storage tank.

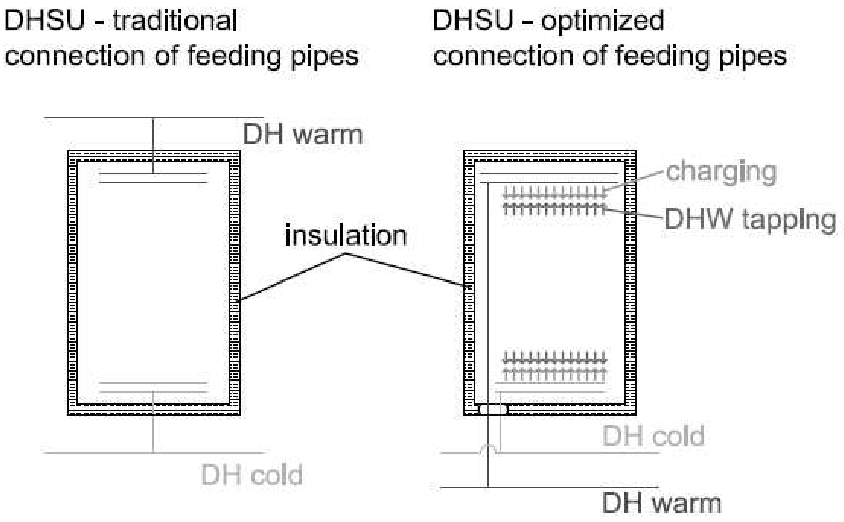


Figure 26 – Left: not optimised solution with thermal bridges and high heat loss; Right: - optimized connection of feeding pipes

Disturbing of stratification by filling/discharging buffer tank

The flow rate during tapping or charging buffer tank can be quite high (see Table 31) causing high turbulence and mixing near inlet/outlet and thus loose of thermal stratification of stored water. The situation is more critical for small buffer tank than for bigger storage tanks. The solution is to use inlet/outlet "nozzle" with biggest area as possible (ideally covering whole bottom of buffer tank) assuring uniform flow (piston flow) of supplied/draw water.

Table 31 – Preliminary maximal discharging flow rate from buffer tank (temperature of stored water 44°C)

DHN charging flow rate [L/min]	size of the tank [L]	max flow from buffer tank [L/min]	preferred diameter [mm]	height [mm]	max. horizontal velocity [cm/sec]
2	53.2	10.4	250	1083	0.35
3.8	28.2	8.3	250	575	0.28
4.7	23.0	7.3	250	468	0.25
5.5	18.4	6.3	250	374	0.21

The nozzle can have small holes (like shower head) producing laminar piston flow. The risk that holes will get blocked with sediments is lower than in case of using it in DHW storage tank because DH water is treated for reduced sedimentation.

Alternatively this problem can be solved by implementation of a membrane between hot and cold water volumes. It will be solution similar to "expansion vessel" for space heating. The membrane will separate both volumes and prevent mixing of cold and warm water in buffer tank. If a membrane is used, the reheating of water in the buffer cannot be made in traditional way. It is suggested to exploit solution where by-pass capillary tube is welded from outside of the buffer tank and reheating DH water stored in buffer tank. The whole buffer tank should be insulated carefully to force heat transfer from capillary tube to buffer tank. The lifetime of rubber membrane shouldn't be forgotten to investigate.

Shape of the buffer tank
Since compactness was one of the important requirements for development of new substation, the shape of the buffer tank should be designed with regards to that. The idea is to make depth and height of buffer tank similar to dimensions of HEX to allow most effective usage of space in the substation. As an example the HEX XB-37H-40 used in IHEU - Lystrup [1] was taken. The dimensions of HEX are WxDxH - 68x119x525 mm. In Table 32 the heights for the buffer tanks with different volumes and fixed diameter of 250 mm are shown to get impression of possible size of substation. The diameter of buffer tank will increase by adding the insulation by approximately 200 mm more. The optimal combination of height/diameter should be found.

Table 32 – Dimensions of buffer tank with diameter 250mm and different volumes

Volume of buffer tank [L]	**30**	**40**	**50**	**60**
Diameter of buffer tank [mm]	250	250	250	250
Height of buffer tank [mm]	611	815	1019	1222

5.4.5 Optimization of IHEU

Beside optimization of DHSU, IHEU supplied by branch pipe Aluflex 14/14/110 with 10 mm inner diameter was considered. Philosophy of this concept is to use DH pipes with the smallest possible diameter to supply IHEU and thus reduce heat loss mainly from BP while accepting increased pressure drop in BP. It should be mentioned, that this concept will be beneficial only for reduction of heat loss from DHN (mainly BP) and not for smoothing of heat demand in DHN.

The design power for IHEU for typical single-family house is 32.3 kW (cooling 50/18°C) resulting in max. primary flow rate 14,1 L/min. In Table 33 it can be found that design pressure drop in BP Aluflex 20/20/110 (inner media pipe diameter 15 mm) supplying IHEU in Lystrup [1] is 1500 Pa/m. If we want to supply IHEU with Aluflex 14/14/110 with inner diameter 10 mm, pressure drop per meter increase to 11600 Pa/m. It results for 20 m long branch pipe (10 m supply + 10 m return) in total pressure drop 2.33 bar instead of recent 0.3 bar. It shouldn't be forgotten to add also 0.3 bar differential pressure needed for substation.

Table 33 – Comparison between design value for pressure drop in Lystrup for BP 15 mm and 10 mm, for 10 m long BP (10 m supply + 10 m return)

Design flow 32.2 kW = 14.1 L/min		
BP diameter [mm]	10	15
pressure drop [Pa/m]	11633	1514
Total pressure drop S+R [bar]	2.33	0.30
velocity [m/s]	2.99	1.33

The pressure drop 2.33 bar in 10 m BP is considered as very high, but for some cases with differential pressure high enough it can be a good solution. Since LTDH wants to use Aluflex pipes, we should still keep in mind that we are limited by 10 bar maximal pressure.

For cases when differential pressure in DHN is not enough high to overcome additional pressure drop in BP caused by reduced diameter, IHEU can be equipped with booster pump. Commercially available booster pumps for single-family DH substation can supply head pressure of 5 mH_2O, i.e. roughly 0.5 bar. For mentioned concept a booster pump with head pressure 24 mH_2O should be used. Nevertheless recently commercially available pumps with desired head pressure are big (300x200x200 mm) and with low efficiency. Investigation of this concept is ongoing.

5.4.6 Conclusion from optimization of DH substations for DHW heating

- Optimized concept of DH substation with small buffer tank was proposed and investigated

- It was found that traditional DHSU with bigger buffer tank are less flexible to user behaviour differing from design conditions, doesn't use available pressure gradient in the BP and can run out of DHW water.

- Proposed DHSSU is a compact unit with buffer tank size between 20 and 60L, combining advantages of IHEU and DHSU in one concept. For DHN developed concept offers decreased design peak power needed for substations resulting in possibility use pipes with lower diameter ant thus reduce heat loss from DHN. For customers new concept brings high level of DHW comfort and thus it can be seen as an optimal solution for future LTDH networks. It is suggested to continue with research on proposed DHSSU with charging flow rate 5.5 L/min by more detailed simulations. In case of positive results, substation should be built and prototype tested.

- Two solutions, i.e. "comfort bathroom" and "on-demand by-pass", reducing waiting time for DHW and preventing charging of buffer tank with cold water were proposed. By its application, high level of DHW comfort will be reached with good operation costs without need of traditional by-pass which increasing temperature of returning DH water

- The influence of whole-year using of floor heating in bathroom (i.e. comfort bathroom concept) on overheating in a typical low-energy house class 1 (BR06) wasn't found. Air temperature in the bathroom was during major part of a year below 24°C which is seen as comfort temperature for bathroom. The price for operation of comfort bathroom by the consumer was calculated to 270 DKK for period outside heating season. Moreover presented results are for situation keeping by-pass temperature on 45°C because of concept of "continual reheating" of DHSSU. If "continual reheating" principle will not be installed, the minimum available power for continual heating of bathroom will decrease substantially.

- As an alternative to DHSSU concept, IHEU exploiting DHN with available high pressure drop available drop was proposed. Concept is suitable for areas with high pressure drop available high differential pressure (e.g. near main pumping station) which will be anyway throttled in substation anyway. The advantage is in lower price for substation caused by absence of buffer tank and control systems and possibility to use BP with inner diameter 14 mm.

5.5 Conclusions

Limitation of peak power for SH and DHW preparation can lead for considerable reduction of heat loss from DHN because of reduced diameter of DH pipes. Peak power limitation of SH is important for whole DHN because simultaneity factor goes asymptotically to 0.62 even for high number of consumers. A main reduction of peak power should be seen in reduction of heat loss from buildings (envelope, ventilation system). For buildings equipped with floor heating system, peak power for SH can be reduced by continual supply of heating water up to 40% in comparison with traditional on/off-control strategy. It results in lower temperatures of DH water returning to DH, in savings and in higher thermal comfort of occupants. A potential for reduction of peak power for radiators is low and not seen as beneficial for DHN.

The peak power limitation of DHW has bigger influence on “terminal parts” of DHN where simultaneity factor for DHW is high such in branch pipes. Peak power for DHW is defined by type of DH in-house substation. DHSU with buffer offers high potential for limiting of maximal peak loads on DHN in comparison with IHEU. Contrary to DHSU concept the reduction of peak power for SH in case of IHEU (heat exchanger unit) has no influence on design of branch pipes. Design peak power for IHEU is defined by need of 32.3 kW (assuming DHW priority) for DHW while peak power for DHSU is defined by sum of power needed for DHW and SH.

Proposal for optimization of existing DHSU with 120L storage tank was suggested and investigated by reduction of size of buffer tank and by increasing of charging flow rate from DHN. By combination of both mentioned actions volume of buffer tank can be reduced to 20-60L depending on individual parameters. This compact unit called DHSSU can fit more easily to house/flat than original unit with 120L buffer tank. The optimal operation of DHSSU in relation to users comfort and network operation can be achieved by using of by-pass flow for whole year floor heating in bathroom. It was shown that use of “comfort bathroom” do not result in critical overheating even in low-energy houses and it has low operation cost for customer (around 300DKR for summer period of 6 months).

By use of proposed DHSSU concept instead of IHEU maximal peak power for DHW preparation can be decreased and it results in lower diameters of DHN and thus lower heat losses and higher saving of CO2.

6 Other investigated issues

Three conference papers with topic relevant to low-temperature district heating have been written by members of the project group. The papers were presented in 12th International Symposium of District Heating and Cooling (ISDHC) in Tallinn, 2010.

6.1 Steady state heat loss in pre-insulated pipes for low energy district heating

6.1.1 Abstract of the investigated issue

The synergy between highly energy efficient buildings and low-energy district heating (DH) systems is a promising concept for the optimal integration of energy saving policies and energy supply systems based on renewable energy. Distribution heat losses represent a key factor in the design of low-energy DH systems. Various design concepts are considered in this paper: flexible pre-insulated twin pipes with symmetrical or asymmetrical insulation, double pipes, triple pipes. These technologies are potentially energy-efficient and cost-effective solutions for DH networks in low-heat density areas. We start with a review of theories and methods for steady-state heat loss calculation. Next, the article shows how detailed calculations with 2D-modeling of pipes can be carried out by means of computer software based on the finite element method (FEM). The model was validated by comparison with analytical results and data from the literature. We took into account the influence of the temperature-dependent conductivity coefficient of polyurethane insulation foam, which enabled to achieve a high degree of detail. We also illustrate the influence of the soil temperature throughout the year. Finally, the article describes proposals for the optimal design of pipes for low-energy applications and presents methods for decreasing heat losses.

6.1.2 Conclusions

The soil temperature at 0.5 m below the surface varies between 2°C in January-February and 14°C in July-August, for Danish conditions. This knowledge can be used to better predict the winter peak load and the temperature drop in the distribution line during summer. The slab-model for steady state heat loss calculations can be replaced, in case of small size distribution/service pipes, by a model where the effect of the soil is represented by a circular soil layer around the district heating pipe. The results confirm that the vertical placement of twin media pipes inside the insulation barely affects the heat transfer, in comparison to the horizontal placement; the difference between the two configurations is less than 2% for the considered cases. We proposed a FEM model that takes into account the temperature-dependency of the thermal conductivity of the insulation foam; in this way we enhanced the accuracy of the heat transfer calculation among pipes embedded in the same insulation. We applied the model to propose optimized design of twin pipes with asymmetrical insulation, double pipes and triple pipes. We proved that the asymmetrical insulation of twin pipes leads to lower heat loss from the supply pipe (from -4% to -8%), leading to a lower temperature drop; next the heat loss from the return pipe can be close to zero. It is possible to cut the heat losses by 6-12% if an optimal design of double pipes is used instead of traditional twin pipes, without increasing the investment costs. The development of an optimized triple pipe solution was also reported. It is suitable for low-energy applications with substations equipped with heat exchanger for instantaneous production of domestic hot water.

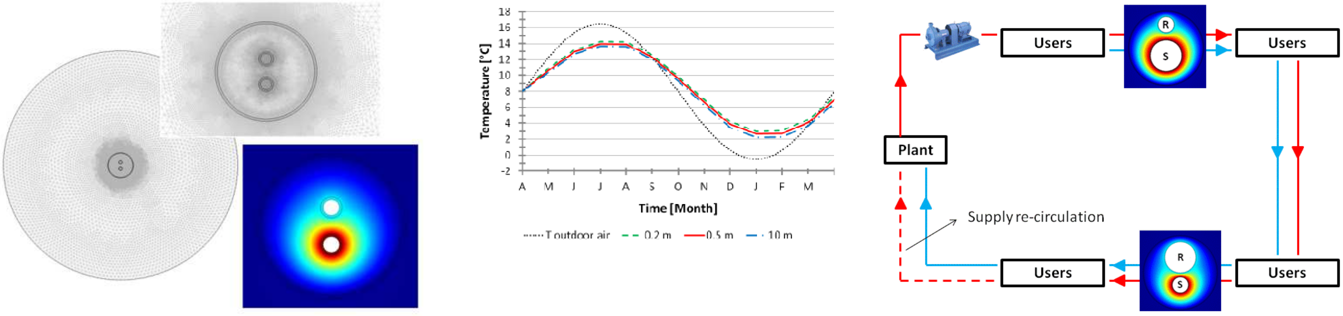


Figure 27 - FEM model (left). Soil temperature (up). double pipe network (right).

See further in appendix 5.

6.2 Design of low temperature district heating network with supply water recirculation

6.2.1 Abstract of the investigated issue

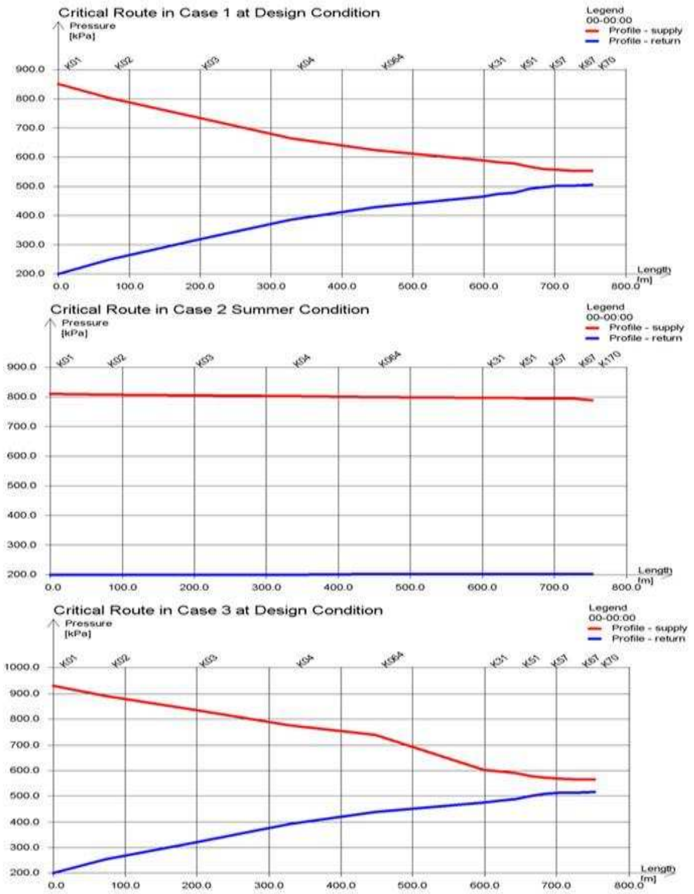
The focus on continuing improving building energy efficiency and reducing building energy consumption brings the key impetus for the development of the new generation district heating (DH) system. In the new generation DH network, the supply and return temperature are designed low in order to significantly reduce the network heat loss. Meanwhile, the low network operational temperature can make a better utilization of renewable energy and further improve the CHP plant efficiency. Though the designed return temperature is low, it may increase considerably when the heating load becomes low and the by-pass system starts to function. The aim of this paper is to investigate the influence of by-pass water on the network return temperature and introduce the concept of supply water recirculation into the network design so that the traditional by-pass system can be avoided. Instead of mixing the by-pass water with return water, the by-pass water is directed to a separated circulation line and returns back to the plant directly. Different pipe design concepts were tested and the annual thermal performances for a selected residential area were evaluated with the commercial program TERMIS. The simulation program calculates the heat loss in the twin pipe as that in the single pipe. The influence of this simplification on the supply/return water temperature prediction was analyzed by solving the coupled differential energy equations.

6.2.2 Conclusions

A preliminary study was conducted on the influence of by-pass flow on the network return water temperature in a designed low temperature DH network. Three network design scenarios which include the reference case, by-pass water recirculation, and double pipeline supply were investigated for each house installation. Figure 1 shows the network pressure distribution along the critical route for the three scenarios with the instantaneous heat exchanger in-house installation.

The simulation showed that the network return temperature will increase due to the direct mixing of supply water and return water. It was observed that, the network by-pass not only increases the return pipeline heat loss in the summer condition, but also, which is more important, cause significant network heat loss due to the un-utilized by-pass water flow.

The introduction of a third pipeline for by-pass water recirculation will decrease the network return temperature and recover the by-pass water at the temperature close to the plant supply temperature during by-pass seasons. However, extra heat loss has to be born due to the extra pipeline. The highest heat loss was found for the double pipe supply case.
The simulation program simplifies the twin pipe heat transfer prediction as a single pipe. The temperature prediction errors due to the single pipe assumption were analyzed through solving the coupled supply/return pipe differential energy equations. It was found that the prediction errors increase with increase the allowable network temperature drop. Considerable error was found for the return pipe at high ground temperature.



Critical Route in Case 1 at Design Condition

Critical Route in Case 2 Summer Condition

Critical Route in Case 3 at Design Condition

Figure 28 - Pressure profile on the critical route for 3 network design scenarios.

See further in appendix 6.

6.3 A direct heat exchanger unit used for domestic hot water supply in a single-family house supplied by low energy district heating

6.3.1 Abstract of the investigated issue

The increasing number of new and renovated buildings with reduced heating requirements will soon make traditional District Heating (DH) systems uneconomic. To keep DH competitive in the future, the heat loss in DH networks needs to be reduced. One option is to reduce the supply temperature of DH as much as possible. This requires a review of the behaviour of the whole domestic hot water (DHW) supply system with focus on the user comfort and overall costs. The paper describes some practical approaches to the implementation of this Low-Energy District Heating (LEDH) concept. It reports on the testing of the dynamic behaviour of an Instantaneous Heat Exchanger Unit (IHEU) designed for DHW heating and space heating in detached family houses supplied by LEDH ensuring an entry-to-substation temperature of 51 °C. We measured the time it takes for the IHEU to produce DHW with a temperature of 42 °C and 47 °C when the tap is opened. Measurements were made for control strategies using internal and external by-pass and no by-pass. Our results show the importance of keeping the branch pipe warm if comfort requirements are to be fulfilled, but this involves higher user costs for heating. To increase user comfort without increasing costs, we propose the whole-year operation of floor heating in bathrooms, partly supplied by by-pass flow.

6.3.2 Conclusions

Since produced DHW has temperature lower than 50°C there should be special attention about Legionella. In the LTDH concept it is solved by instantaneous preparation of DHW (not storing of DHW) and limiting of volume of DHW bellow 3L (due to German standard DVGW W551). The tested IHEU is equipped with highly efficient heat exchanger assuring for the identical primary and secondary flow rates temperature drop only 4K, i.e. from DH water with temperature 50°C DHW with temperature 46°C is produced. The time needed for IHEU to produce DHW with desired temperature (42°C or 47°C) is defined by using the control strategy and is shown in the table.

Table 34 - Measurement results for the low-energy heat exchanger

	case number and description	T_{11} (°C)	T_{42} (sec)	T_{45} (sec)	T_{47} (sec)	T_{12} (°C)	T_{12AVG} (°C)	T_{HEX-UP} (°C)	$T_{HEX-DOWN}$ (°C)
NO BY PASS	1 -after long idling, no by-pass (BYP)	50.1	12	18	25	16.2	19.5	20.4	21
EXTERNAL BY-PASS	2 -after long idling, just before BYP was expected to open again	49.6	11	16	22	30.1	19.3	21.5	21.4
	3 - after long idling, just after BYP closed	50.6	8.5	12	16.5	42.6	19	*29*	*26*
	4 - 5 minutes after previous tapping finished	50.8	7	10	14	25	19.1	22.3	37.4
INTERNAL BY-PASS	5 - just before BYP was expected to open (3 min after prev. tapp. finished))	50.5	6	10	14	19.5	19.1	22.6	38
	6 - anytime, when BYP was already in operation	49.3	1.5	3.5	7	47.3	18.4	44	45.5

It can be concluded that shortest recovery time was achieved for solution with internal by-pass (case 5 and 6), keeping heat exchanger on relatively high temperature and longest for solution without the by-pass (case 1). Nevertheless internal by-pass has high energy consumption and resulting in sending not sufficiently cooled water back to DH network. As an optimal solution for user comfort and energy efficient operation can be seen a solution with external by-pass resulting in recovery time between 7–11 seconds (cases 2-4). Solution with external by-pass can be furthermore combined with whole year operation of floor heating in bathroom and thus additionally improve comfort and economy of IHEU. For further reduction of recovery time, more efficient heat exchanger with lower thermal mass and new control system designed especially for LTDH operation can be developed.

See further in appendix 7.

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8 Appendix

Appendix 1:
"Fjernvarmeforsyning til lavenergibebyggelse - Undersøgelse af nye krav til design af ledningsnet og nye tekniske løsninger", AffaldVarme Århus, november 2010

Appendix 2:
"Kunders huse sat under lup i Århus". Article in "Fjernvarmen" No. 9, 2010.

Appendix 3:
Lavenergifjernvarme til eksisterende byggeri – Langøvænget, Århus, Mette Schroeder, Danish Technical University, February 2011

Appendix 4:
Lavenergifjernvarme til eksisterende byggeri – Næstved, Mette Schroeder, BSc project, Danish Technical University, September 2010

Appendix 5:
"Steady state heat loss in pre-insulated pipes for low energy district heating". Conference paper by Alessandro Dalla Rosa, H. Li and Svend Svendsen - Civil Engineering Department, Technical University of Denmark. 11th symposium for district heating and cooling, Tallinn, September 2010.

Appendix 6:
"Design of low temperature district heating network with supply water recirculation". Conference paper by Hongwei Li, Alessandro Dalla Rosa and Svend Svendsen - Civil Engineering Department, Technical University of Denmark. 11th symposium for district heating and cooling, Tallinn, September 2010.

Appendix 7:
"A direct heat exchanger unit used for domestic hot water supply in a single-family house supplied by low energy district heating ". Conference paper by Marek Brand and Svend Svendsen - Technical University of Denmark; Jan Eric Thorsen - Danfoss District Energy; And Christian Holm Christiansen - Danish Technological Institute. 11th symposium for district heating and cooling, Tallinn, September 2010.

Appendix 1

Fjernvarmeforsyning til lavenergibebyggelse

Undersøgelse af nye krav til design af ledningsnet

og nye tekniske løsninger.

Version:	1. udgave
Udgivelsesdato:	Revideret 22-11-2010 til EUDP lavtemperatur fjernvarme
Udarbejdet:	Lavenergigruppen/Planlægning og Projekt/MH

Indhold

1. Baggrund

I forbindelse med nye skrappe krav til bygningers energiforbrug i lavenergibyggerier KL.1, KL.2 og passiv bygning jf. Bygningsreglement 2008, står vi som fjernvarmeforsyningsselskaber overfor vigtige udfordringer. Det gælder for hele fjernvarmebranchen, at vi må revurdere det lange traditionelle koncept for design og dimensionering af ledningsnettet. Hvis fjernvarmeforsyning fremover skal forsyne lavenergibyggeri, er der behov for nytænkning og nye tekniske løsninger til anlægsdimensioneringen, så det fortsat er miljø- og driftsøkonomisk rentabelt at forsyne lavenergibyggeri med fjernvarme.

Lavenergigruppen er etableret i samarbejdet mellem flere varmeforsyningsselskaber med fokus på at videreudvikle et designkoncept ved anvendelse af nye teknologier, materialer og driftsformer.

Gruppen består af:

- Mette Rude(MR): Fjernvarme Århus
- Allan Jessen(AJ): Fjernvarme Århus
- Minh Huynh(MH): Fjernvarme Århus
- Grethe Føns Hjortbak(GFH): Varmeplan Århus
- Jiehua Mao(JM): Varmeplan Århus
- Thorkild Kjærsgaard(TK):Skanderborg Fjernvarme
- Peter Jensen(PJ): Hørning Fjernvarme
- Lars Lisbjerg(LL): Odder Fjernvarme
- Jan Roer Pedersen(JRP): Odder Fjernvarme
- Flemming Strange(FS): Lystrup Fjernvarme

Gruppens arbejde er, med udgangspunkt i to udvalgte områder med forskellige lavenergibebyggelsestyper, at kunne stille nye krav til anlægsdesign og anlægsdimensionering.

2. Opgavebeskrivelse

2.1 Formål

Vi skal finde en fælles retningslinje for udbygningen af fjernvarmenettet med hensyn til design af ledningsnet og ”design” af tekniske bestemmelser for lavenergibebyggelse.

2.2 Mål og delmål

Med udgangspunkt i beregninger for ”kritiske” nye kunder, her defineret primært som kunder i åbent-lavt byggeri, sekundært også tæt-lavt byggeri, skal vi som udgangspunkt finde en fælles holdning til vilkår for udbygningen for så vidt designparametre for ledningsnettet og for brugerinstallationerne.

I opgaven optræder følgende delmål.

- Vurdering af faktorer med afgørende betydning for design af net og brugerinstallationer.
- Vurdering af hvilke forhold(input), der flytter mest i forhold til effekt ved design af net og brugerinstallationer.
- Vurdering af ønsket sikkerhedsmargin ved design af net og brugerinstallationer.
- Vurdering af bebyggelsestæthed – hvilken konsekvens i forhold til design af net og brugerinstallationer. Fokus på tæt-lavt og åben-lavt byggeri.
- Vurdering af hvilke designparametre, der giver rammen for forslag til tekniske bestemmelser.
- Klarhed over gevinster/ulemper ved optimeret metode frem for den ”sædvanlige” metode.
- Diskussion og konklusion omkring praktiske/økonomiske/realistiske hensyn i relation til fælles valg.
- Alternativer værdisættes ud fra en selskabsøkonomisk vinkel.

2.3 Afgrænsning

I nærværende opgave analyseres to områder:

- Ellebæk Parkvej er tæt-lavt byggeri i Lystrup. Et område, der er bebygget med huse, der ikke er opført som lavenergi. Området er valgt for at kunne sammenholde de teoretiske beregningsresultater for lavenergibyggeri med faktuelle forhold for ikke-lavenergibyggeri.

- Solbjerg Hedevej er åbent-lavt byggeri i Solbjerg. Et område, der er lokalplanlagt til Lavenergiklasse 1, men et område der endnu ikke bebygget. Området er valgt for at kunne sammenholde data for ”sådan plejer vi at gøre det i Varme” til sådan ser et totalt optimeret anlæg ud.

Der er anvendt fælles input til optimerede modeller for de to områder. Input primært med baggrund i EFP2007 rapport: ”Udvikling af demonstration af lavtemperaturfjernvarme til lavenergibyggeri”.

Beregningsværktøj er Termis, hvor COWI regner på Ellebæk Parkvej og Planlægning og Projekt regner på Solbjerghedevej.

3. Dimensioneringsgrundlag

3.1 Temperaturprofiler

Beregningsforudsætninger fastlægges efter Varmeplan Danmark, EFP projekt og ST2:

Bebyggelse:	Beregningerne baseres på effektbehov pr. hus. Formålet er at få et billede af Effekt (kW pr. bolig) over Tid (ændring af energiramme og klasse hus jf. BR2010…) og hvornår det er rentabelt med fjernvarmeforsyning. Resultaterne sammenholdes derefter med energiramme og forskellige muligheder for anvendelser af vedvarende energi teknologier kan kombineres.
Maksimal design fremløb:	90º C
Årsmiddel fremløb:	60º C
Design returløb:	35º C
Årsmiddel returløb:	30º C
Dimension:	Min. 10 mm indvendig
Flow:	Maks. vandhastighed er 2 m/s i alle rør.
Bebyggelsesart:	Parcelhuse 170 m^2 og tæt-lav 130 m^2.
Stikledning:	Stikledningslængde for tæt-lav bebyggelse som på tegningen og 15 m for parcelhusbebyggelsen.
Samtidighed:	Jf. Varmeståbi, Samtidighedsfaktor´s formel/tabel angives.
Tilslutningsgrad:	Bebyggelser regnes for 100 % tilsluttet
Veksler:	32,3 kW-, 20 kW veksler og fjernvarmeunit skal beregnes hver for sig i et 6 bar-system.
Rørtype:	Anvendelse af dobbeltrør serie 2 i alle dimensioner.

3.2 Dimensionerende situation

Ledningsnettet dimensioneres efter efterårslast, som svarer til 60 procent af varmebelastning og fuld brugsvandsbelastning.

Beregningskriterier i termis:

Omløb 56,5 ° C hos forbruger

Dødbånd 2,5° C

Fremløbstemperatur 60° C

Returtemperatur 35° C

Mindste temperatur hos forbrugeren 55° C

Jordtemperatur varierer mellem 1,8° og 16,5° C

Årsbenyttelsestid på 2000 timer

3.3 Energiforbrug

Varmeforbruget er beregnet i forhold til Energirammen for klasse 1 og klasse 2 boliger, som svarer til henholdsvis 50 % og 70 % af varmeforbruget i standard boliger i BR08. Energikravet for det maksimale årlige energiforbrug ses nedenfor.

Bygningsreglement Stk. 1

Lavenergiramme for boliger, kollegier, hoteller m.m.
En bygning, hvis samlede behov for tilført energi til opvarmning, ventilation, køling og varmt brugsvand pr. m^2 opvarmet etageareal ikke overstiger 35 kWh/m^2 pr. år tillagt 1100 kWh pr. år divideret med det opvarmede etageareal, kan klassificeres som en lavenergibygning klasse 1.

(7.2.4.1, stk. 1) For lavenergibygninger klasse 1 er energirammen:

(35 + 1100/A) kWh/m^2 pr. år, hvor A er det opvarmede etageareal.

Bygningsreglement Stk. 2

En bygning, hvis samlede behov for tilført energi til opvarmning, ventilation, køling og varmt brugsvand pr. m^2 opvarmet etageareal ikke overstiger 50 kWh/m^2 pr. år tillagt 1600 kWh pr. år divideret med det opvarmede etageareal, kan klassificeres som en lavenergibygning klasse 2.

(7.2.4.1, stk. 2) For lavenergibygninger klasse 2 er energirammen:

(50 + 1600/A) kWh/m^2 pr. år, hvor A er det opvarmede etageareal.

Tabel 3.3 Lavenergiramme for boliger

Energiforbrug Ellebæk Parkvej i Lystrup:

130 m^2 rækkehus lavenergikl. 1 bolig

Rumopvarmning	3.036	kWh/år
Brugsvand	1.704	kWh/år
I alt	4.740	kWh/år

130 m^2 rækkehus lavenergikl. 2 bolig

Rumopvarmning	5.486	kWh/år
Brugsvand	1.704	kWh/år
I alt	7.190	kWh/år

Energiforbrug Solbjerg Hedevej i Solbjerg:

170 m^2 parcel hus lavenergikl.1 bolig

Rumopvarmning	3.632	kWh/år
Brugsvand	2.228	kWh/år
I alt	5.860	kWh/år

170 m^2 parcel hus lavenergikl.2 bolig

Rumopvarmning	6.682	kWh/år
Brugsvand	2.228	kWh/år
I alt	8.910	kWh/år

3.4 Tilslutningseffekt

Tilslutningseffekten er regnet ud fra det årlige varmeforbrug og en årsbenyttelsestid på 2000 timer. Effekten anvendes i den årlige varmeproduktionsberegning i Termis.

Tilslutningseffekt for Ellebæk Parkvej i Lystrup:

- 130 m^2 rækkehus kl. 1 bolig er 2,37 kW
- 130 m^2 rækkehus kl. 2 bolig er 3,60 kW

Tilslutningseffekt for Solbjerg Hedevej i Solbjerg:

- 170 m^2 parcelhus kl.1 bolig er 2,93 kW
- 170 m^2 parcelhus kl.2 bolig er 4,46 kW

4. Ellebæk Parkvej i Lystrup

4.1 Termis modelberegning af Ellebæk Parkvej

Se *"TERMIS modelberegning af Ellebæk Parkvej"*

Dokument nr. P-57530-A-1

Version 1.00

Udgivelsesdato: juli 2009 af COWI.

Udarbejdet: MRLI

Kontrolleret: TAO

Godkendt: TAO

5. Solbjerg Hedevej i Solbjerg

5.1 Bebyggelse

På det udvalgte område ved Solbjerg Hedevej er det lokalplanlagt at opføre 104 parcelhuse på hver 170 m^2 som lavenergiboliger.

Figur 5.1 Nyt område for lavenergibyggeri

5.2 Scenariebeskrivelse

Vi vil i dette projekt gå et skridt yderligere for at få maksimal udnyttelse af den antagne trykkapacitet i nettet på 6 bar ved fuldoptimering af anlægsdesign. Som udgangspunkt er ledningsnettet dimensioneret efter forudsætninger i *"afsnit 3.2 Dimensionerende situation"*. Ledningsnettet regnes herefter med spidslast og et differenstryk på 5 bar i Termis, hvor ledninger bliver yderligere reduceret efter det overskudstryk, der er i nettet.

Målet er at få undersøgt forhold mellem det traditionelle anlægsdesign og det fuldoptimerede anlæg. Det er sådan, at jo mere vi optimerer vores anlæg, des større driftsmæssig udfordring og risiko er der. Vi vil i den sammenhæng bestemme den maksimale reducering af årsvarmetab ved forskellige beregningsscenarier og hvor meget skal vi ændre på vores traditionelle dimensioneringsprincip i forhold til varmetabsbesparelsen, så det stadig er driftssikret og miljøøkonomisk rentabelt at forsyne området med lavenergibebyggelsen.

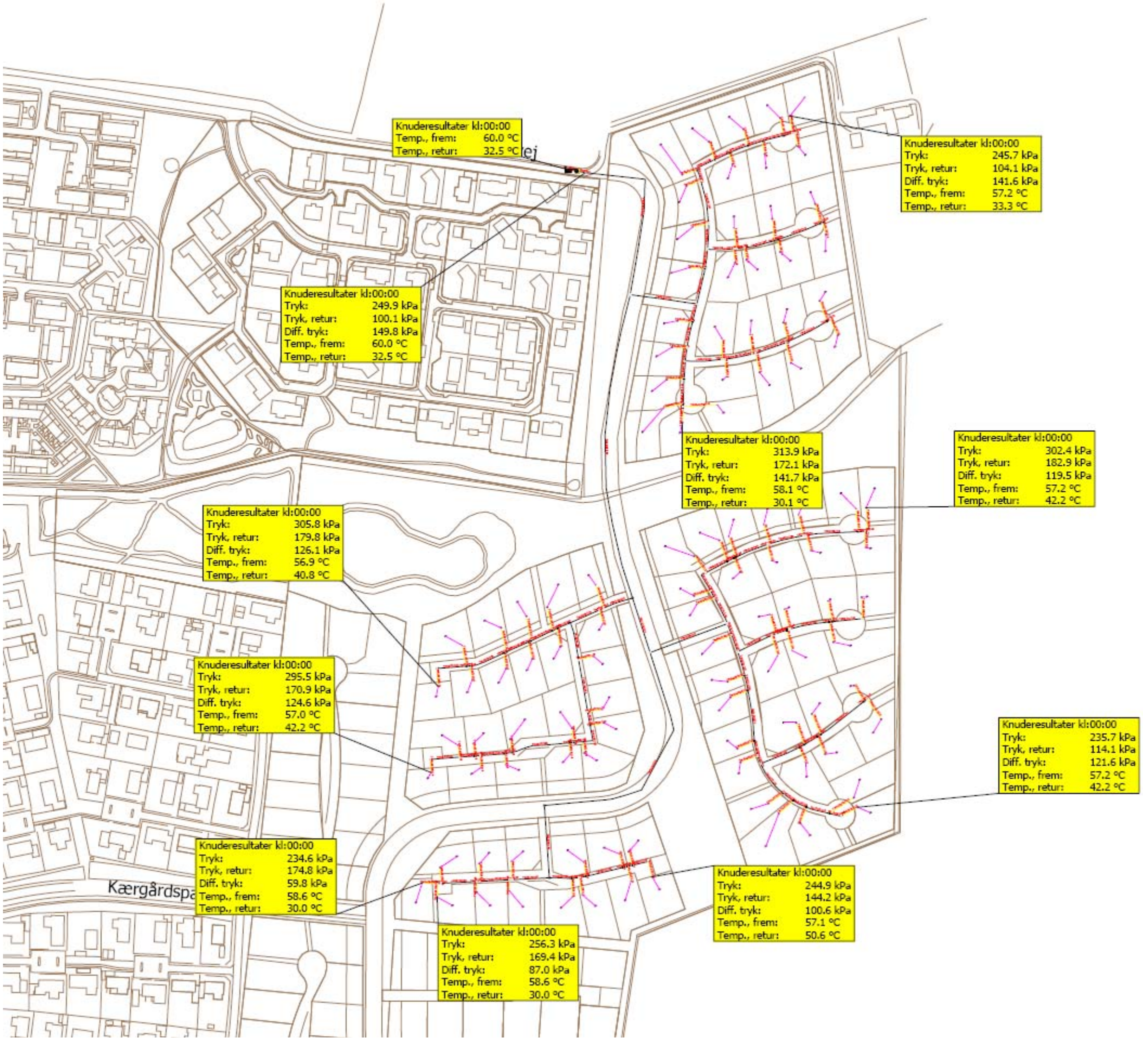
5.2.1 Brugerinstallation

Følgende forbrugerinstallationer anvendes i projektet:

- 32,3 kW veksler, der jf. DS439, skal kunne dække samtidig forbrug fra en bruser og en køkkenvask.
- 20 kW veksler, der svarer til varmeeffekt for en bruser
- 110 liter, fjernvarmebeholderunit, som er en ny type installation, hvor brugsvandseffekten er fordelt over hele døgnet. Dette vil medføre mindre stikledninger end veksleren og hermed mindre varmetab i ledningsnettet.

5.2.2 Beregningsscenarie

Følgende scenarier beregnes og analyseres termisk og hydraulisk forhold i et Termis-program.



Figur 5.2.2 Dimensionering af ledningsnettet for lavenergiområdet ved Solbjerg i Termis

Trin 1: Ledningsnet dimensioneres efter max. tryk 6 bar og differenstryk 5 bar med årskørselberegning i Termis på årsmiddel fremløb 60^0 C og 30^0 C på returløb. I alle løsningsmodeller med nye forudsætninger bliver stikledninger dimensioneret til Twinrør Ø16/16/110 på nær løsningsmodel nr.7, som dimensioneres til dobbeltrør Ø20/26/125.

1. **Lavenergiklasse 2 med 32,3 kW veksler** *(nye forudsætninger + 32,3 kW varmtvandsbehov+2,7 kW tilslutningseffekt)*
2. **Lavenergiklasse 2 med 20 kW veksler** *(nye forudsætninger + 20 kW varmtvandsbehov+2,7kW tilslutningseffekt)*
3. **Lavenergiklasse 2 med fjvunit** *(nye forudsætninger +4,5 kW tilslutningseffekt)*
4. **Lavenergiklasse 1 med 32,3 kW veksler** *(nye forudsætninger + 32,3 kW varmtvandsbehov+1,8kW tilslutningseffekt)*
5. **Lavenergiklasse 1 med 20 kW veksler** *(nye forudsætninger + 20 kW varmtvandsbehov+1,8kW tilslutningseffekt)*
6. **Lavenergiklasse 1 med fjvunit** *(nye forudsætninger + 2,93 kW tilslutningseffekt)*
7. **Lavenergiklasse 2 med 32,2 kW veksler** *(nuværende princip +tryktab max. 50Pa/m i hovedledninger.)*

Trin 2: Ledningsnet dimensioneres til varmtvandsbeholder.

8. **Lavenergiklasse 1 med varmtvandsbeholder** (*nuværende princip +tryktab max. 50Pa/m i hovedledninger.)*
9. **Lavenergiklasse 1 med varmtvandsbeholder** *(nye forudsætninger + effekt af varmtvandsbeholder*

5.3 Resultater

Ved anvendelse af Termis-program udregnes termiske og hydrauliske forhold for hver enkelt af de løsningsmodeller indenfor forudsætningsrammen i ”*afsnit 3. Dimensioneringsgrundlag*”. Resultaterne for pumpeeffekt, temperatur på fremløb og returløb på centralen samt maks./min. flow og varmetab kan se på vedlagt /bilag 1/

5.3.1 Årsvarmetab

For at kunne bestemme det årlige varmetab i ledningsnettet må varighedskurven inddeles i 9 perioder, hvor 1. perioden svarer til en spidslastssituation og 9. perioden svarer til sommerlast uden for opvarmningssæsonen *(se tabel5.3.1A og B).*

Periode nr.		Interval		Faktor	Effekt	Jord temp
	Timer	Fra	Til	[-]	[kW]	[°C]
1	0	0	0	1,00	307,65	1,8
2	740	0	740	0,72	221,29	1,8
3	670	740	1410	0,41	125,11	2,4
4	750	1410	2160	0,34	103,37	2,6
5	750	2160	2910	0,25	78,02	4,1
6	730	2910	3640	0,17	53,18	7,4
7	730	3640	4370	0,11	34,70	8,0
8	442	4370	4812	0,08	24,05	11,0
9	3948	4812	8760	0,07	20,37	16,0

Tabel 5.3.1A: Perioder og timer for lavenergiklasse1 for bygning på 170 m^2

Periode nr.		Interval		Faktor	Effekt	Jord temp
	Timer	Fra	Til	[-]	[kW]	[°C]
1	0	0	0	1,00	467,78	1,8
2	740	0	740	0,74	345,45	1,8
3	670	740	1410	0,44	205,76	2,4
4	750	1410	2160	0,36	167,28	2,6
5	750	2160	2910	0,26	122,40	4,1
6	730	2910	3640	0,17	78,45	7,4
7	730	3640	4370	0,10	48,53	8,0
8	1294	4370	5664	0,06	29,94	13,5
9	3096	5664	8760	0,04	20,74	16,5

Tabel 5.3.1B: Perioder og timer for lavenergiklasse2 for bygning på 170 m^2

Årskørselsberegninger simuleres i Termis. Den årlige varmeproduktion og varmetab for forskellige løsningsmodeller udregnes og sammenholdes i nedenstående tabel 5.3.1C.

Model	Samlet produktion	Heraf total ledningstab	Varmetab	Pumpe-energi
	kWh	kWh	%	kWh
Model nr. 1 - Klasse 2 - 32,3 kW veksler max. 6bar	982.415	176.007	17,9	3.998
Model nr. 2 - Klasse 2 - 20,0 kW veksler max. 6bar	977.307	170.899	17,5	4.740
Model nr. 3 - Klasse 2 - Fjernvarmeunit max. 6bar	960.704	154.296	16,1	4.495
Model nr. 4 - Klasse 1 - 32,3 kW veksler max. 6bar	712.843	174.023	24,4	3.806
Model nr. 5 - Klasse 1 - 20,0 kW veksler	710.534	171.714	24,2	4.897
Model nr. 6 - Klasse 1 - Fjernvarmeunit max. 6bar	704.551	165.731	23,5	4.960
Model nr. 7 - Klasse 2 -32,3 kW veksler Nuværende princip 50Pa/m	1.006.338	199.930	19,9	2.753
Model nr. 8 - Klasse 1- Varmtvandsbeholder 50Pa/m	730.984	192.163	26,3	2.936
Model nr. 9 - Klasse 1- Varmtvandsbeholder max. 6bar	710.534	171.714	24,2	4.855

Tabel 5.3.1C: Samlet varmeproduktion og varmetab

5.3.2 Anlægsøkonomi

Pumpe-, bygværk- og styringsomkostninger er ikke medregnet i anlægsudgifter. Anlægsinvestering er kun for rørmaterialer og anlægsarbejde (*se tabel 5.3.2).*

Beskrivelse	Anlægsinvestering i kr.	Beregnet Varmetab i kWh
Model 1: Veksler 32,3 KW klasse 2	12.611.436,16	176.007
Model 2: Veksler 20 KW klasse 2	12.494.455,30	170.899
Model 3: Fjernvarme Unit klasse 2	12.062.526,65	154.296
Model 4: Veksler 32,3 KW klasse 1	12.524.525,43	174.023
Model 5: Veksler 20 KW klasse 1	12.431.559,59	171.714
Model 6: Fjernvarme Unit klasse 1	12.021.444,93	165.731
Model 7: Nuværende princip	14.447.090,32	199.930
Model 8: Varmvandsbeholder 50 Pa/m klasse 1	13.592.855,61	192.163
Model 9: Varmvandsbeholder 6 bar klasse 1	12.431.559,59	171.714

Tabel 5.3.2 Anlægsinvestering

5.4 Sammenfatning

Varmetab: Det største årsvarmetab på 199.930 kWh findes i løsningsmodel nr. 7 (*Nuværende princip med trykgradient på 50 Pa/m i hovedledning*), som forsyner 105 lavenergihuse klasse 2 med årsmiddel fremløb ca. 60^0 C. Det mindste varmetab er 154.296 kWh ved løsningsmodel nr.3, der forsyner det samme område med fjernvarmeunit.

Resultaterne viser også, at vi kunne reducere varmetabet med 13,6 % ved at vælge det fuldoptimerende anlæg i forhold til det traditionelle anlæg, som skal forsyne med lavtemperatur fjernvarme til lavenergiområdet. På nedenstående diagrammer 5.4A og 5.4B illustreres forholdene på disse to løsninger.

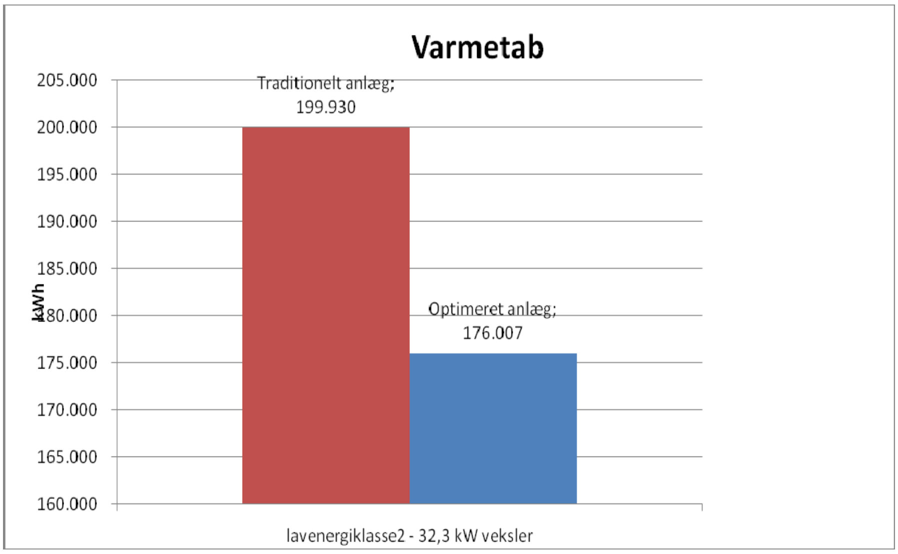


Diagram 5.4A Årsvarmetab for de forskellige løsningsmodeller

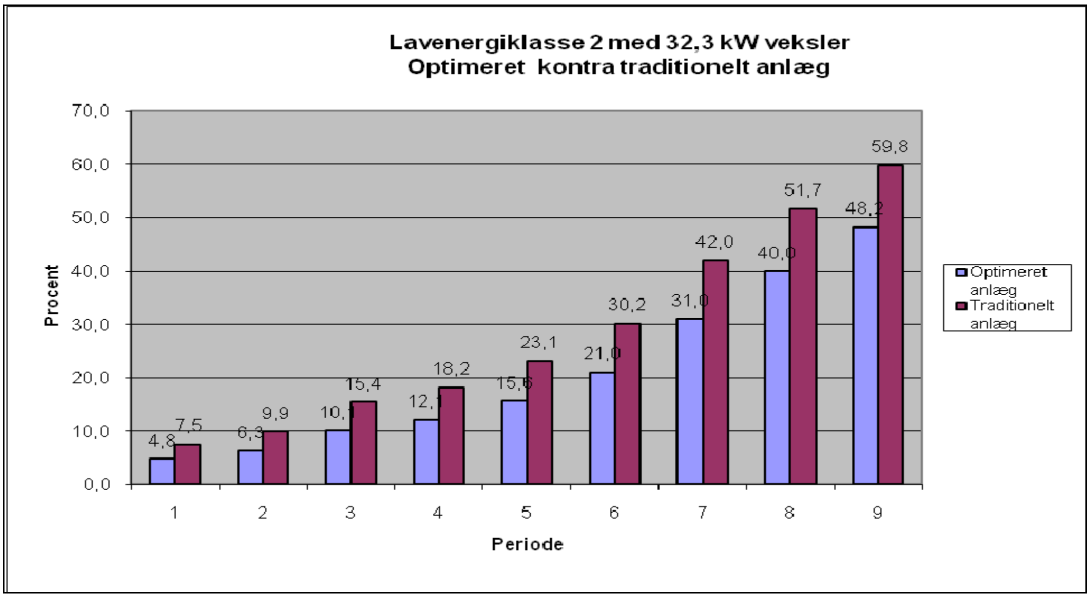


Diagram 5.4B Varmetab i de 9- perioder i procent for de forskellige løsningsmodeller

Der er ikke stor forskel i varmetabet i de optimerede anlæg, da ledningsnettet køres med lavtemperatur på ca. 60^0 C som årsmiddel fremløbtemperatur, høj vandshastighed og små rørdimensioner.

Samlet varmebesparelse for lavenergibyggeri klasse 1: På tabel 5.4 viser varmetab i procent ved forskellige løsninger.

	Beregning	Beskrivelse	Varmetab i %	Årlig prod. i kWh	Årligt varmetab i kWh
Ellebækvej	4	Klasse 1 - 32,3 kW veksler - 6 bar	16,7	567217	94472
	5	Klasse 1 - 20 kW veksler - 6 bar	15,9	561993	89249
	6	Klasse 1 - Fjernvarmeunit - 6 bar	13,4	546119	73375
Solbjerg Hedevej	6	Klasse 1 - Fjernvarme Unit - 6 bar	23,5	704551	165731
	5	Klasse 1 - 20 kW veksler - 6 bar	24,2	710534	171714
	4	Klasse 1 - 32,3 kW veksler - 6 bar	24,4	712843	174023
	8	Klasse 1 - Varmvandsbeholder 50 Pa/m	26,3	730984	192163
	9	Klasse 1 - Varmvandsbeholder - 6 bar	24,2	710534	171714

Tabel 5.4 Varmetab ved forskellige løsningsmodel

Ved 100 % optimeret fjernvarmenet:

Mulig besparelse ved valg af varmtvandsproduktion: (32,3 kW til 20kW)

		Diff. i varmetab i %
Ellebækvej	5,5 %	0,8 %
Solbjerg Hedevej	1,3 %	0,2 %

Mulig besparelse ved valg af varmtvandsproduktion: (20 kW til Fjernvarmeunit)

Ellebækvej	17,8 %	2,5 %
Solbjerg Hedevej	3,5 %	0,7 %

Mulig besparelse ved valg af varmtvandsproduktion: (32,3 kW til Fjernvarmeunit)

Ellebækvej	23,3 %	3,3 %
Solbjerg Hedevej	4,8 %	0,9 %

Forskellen i mulig besparelse skyldes, at der for Solbjerg Hedevej er optimeret yderligere i de strækninger, hvor der er differenstryk til rådighed i spidslastsituation.

I forhold til nuværende dimensioneringsmetode:
Mulig besparelse ved 100 % optimering (v/ varmtvandsbeholder):
Solbjerg Hedevej 10,6 % 2,1 %

Mulig besparelse ved 100 % optimering (v/ Fjernvarmeunit):
Solbjerg Hedevej 13,8 2,8 %

Samlet varmebesparelse for lavenergibyggeri klasse 2:

	Beregning	**Beskrivelse**	**Varmetab i %**	Årlig prod. I kWh	Årligt varmetab i kWh
Ellebækvej	1	Klasse 2 - 32,3 kW veksler - 6 bar	11,8	801276	94536
	2	Klasse 2 - 20 kW veksler - 6 bar	11,3	797105	90365
	3	Klasse 2 - Fjernvarmeunit - 6 bar	9,6	782116	75376
Solbjerg Hedevej	7	Klasse 2 - 32,3 kW veksler - 50 Pa/m	19,9	1006338	199930
	3	Klasse 2 - Fjernvarme Unit - 6 bar	16,1	960704	154296
	2	Klasse 2 - 20 kW veksler - 6 bar	17,5	977307	170899
	1	Klasse 2 - 32,3 kW veksler - 6 bar	17,9	982415	176007

Ved 100% optimeret fjernvarmenet:
Mulig besparelse ved valg af varmtvandsproduktion: (32,3 kW til 20kW) Diff. i varmetab i %

Ellebækvej 4,4 % 0,5 %

Solbjerg Hedevej 2,9 % 0,4 %

Mulig besparelse ved valg af varmtvandsproduktion: (20 kW til Fjernvarmeunit)
Ellebækvej 16,6 % 1,7 %

Solbjerg Hedevej 9,7 % 1,4 %

Mulig besparelse ved valg af varmtvandsproduktion: (32,3 kW til Fjernvarmeunit)
Ellebækvej 20,3 % 2,2 %

Solbjerg Hedevej	12,3 %	1,8 %

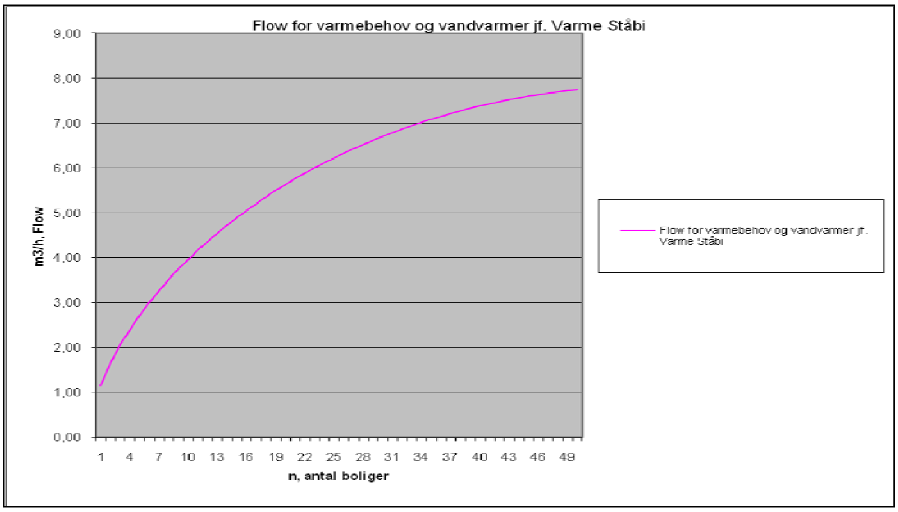
I forhold til nuværende dimensioneringsmetode:
Mulig besparelse ved 100% optimering (v/ 32,3 kW veksler):

Solbjerg Hedevej	12,0 %	2,0 %

Mulig besparelse ved 100% optimering (v/ Fjernvarmeunit):

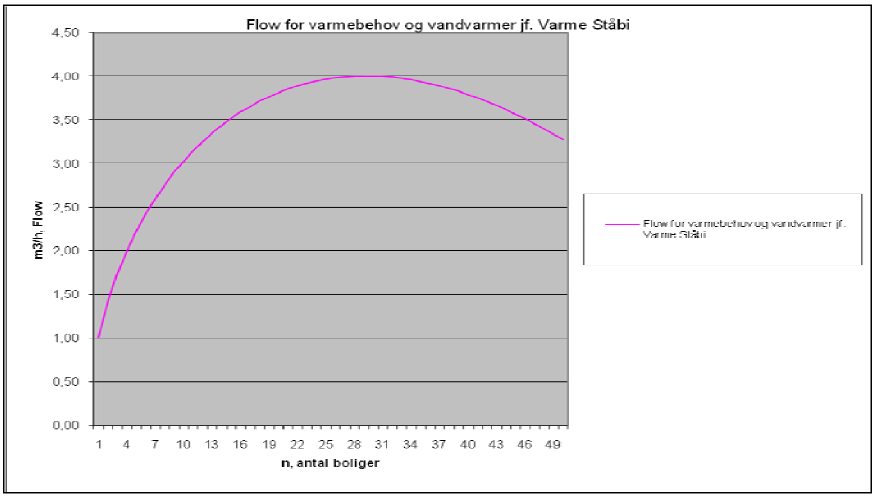
Solbjerg Hedevej	22,8	3,8 %

Samtidighed af tilslutningseffekt og brugsvandseffekt: Vi kan på baggrund af beregningerne konstatere, at formel for samtidighed af tilslutningseffekter og samtidighed af tillæg for brugsvand i ”*Varme Ståbi, 4 udgave*” må revurderes ved anvendelse til dimensionering af ledningsnettet for området med lavenergibyggeri. Formlerne er generelt skrevet til standardbolig med ca. 8,5 kW i tilslutningseffekt og 32,3 kW i brugsvandseffekt. På Figur 5.4A er der vist sammenhæng mellem antal forbruger og det samlede flow.



Figur 5.4A Flowkurve for 8,5 kW tilslutningseffekt og 32,3 kW brugsvandseffekt

Ved lavenergibebyggelsen er tilslutningseffekten for klasse 1 hus reduceret med ca.50 %, det medfører, at kurven for det beregnede flow til rørdimensionering ændrer karakter ved den 29. forbruger. Figur 5.4B viser sammenhæng mellem antal forbruger og det samlede flow ved lavenergihus klasse 1 med 3,5 kW i tilslutningseffekt og 32,3 kW i brugsvandseffekt.



Figur 5.4B Flowkurve for 3,5 kW tilslutningseffekt og 32,3kW brugsvandseffekt

For at kunne bestemme den dimensionerede varmeeffekt til rørdimensionering har vi i dette projekt valgt at tillægge 60 procent af tilslutningseffekten for hver forbruger efter kurven topper.

Anlægsøkonomi: Der er ikke stor forskel i anlægsudgifter for de optimerede anlæg. Den største anlægsbesparelse findes mellem den traditionelle løsning og det fuldoptimerende anlæg. Ved opførelsen af det traditionelle anlæg er ledningsudgiften 20 procent højere i forhold til det fuldoptimerende anlæg. Men vi må også regne med, at driftsudgiften for det optimerede anlæg vil stige. Dette skyldes, at der kræves mere styring og overvågning af det fuldoptimerede anlæg.

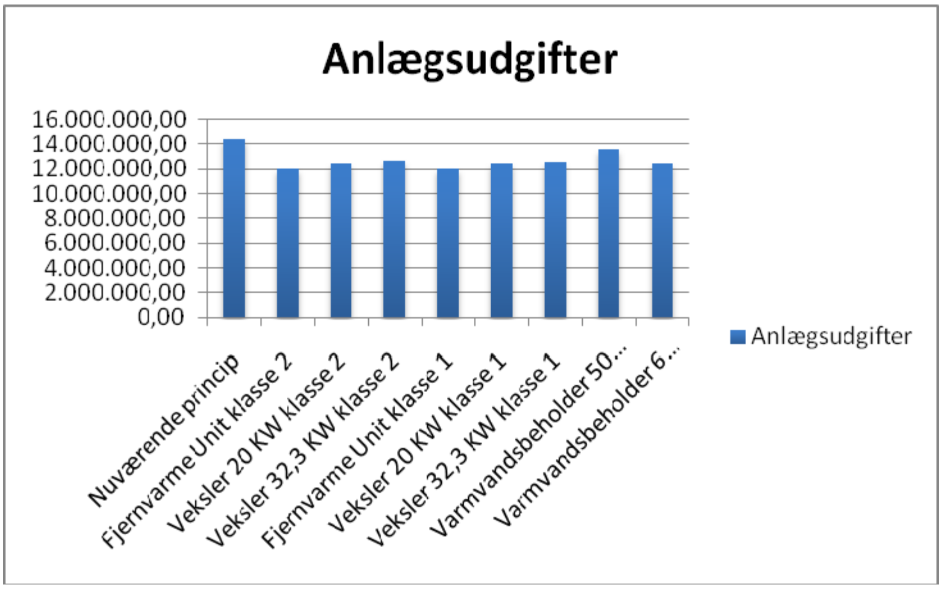


Diagram 5.4C Anlægsinvestering og driftsudgift til ledningstab over 30 år

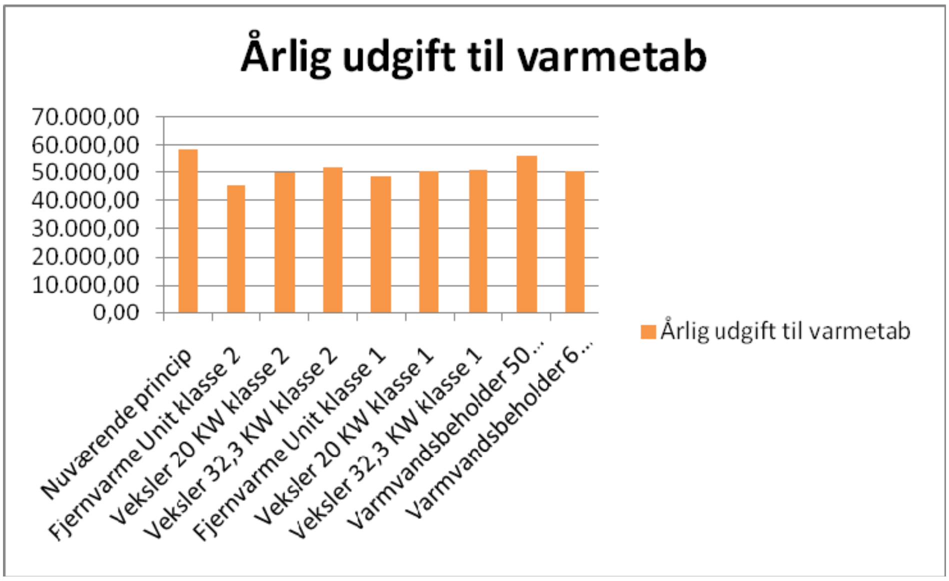


Diagram 5.4.D Årlig udgift til varmetab

Kritiske ruter i ledningsnettet: De mange kritiske ruter i ledningsnettene, tilhørende beregningsscenarier 1 til 6 fra *”Trin 1- se afsnit 5.2.2”*, kan give en større udfordring i driftsstyringen af nettet. Årsagen er, at ledningsdimensionerne bliver reduceret efter det differenstryk, der er til rådighed i nettet. Det medfører, at mange ledningstrækninger har det samme differenstryk hos de sidste forbrugere. Da det også er et bebyggelsesområde med kun 105 boliger med lav tilslutningseffekt, har samtidighed for brugsvandseffekten afgørende betydning for, hvilken strækning der bliver den kritiske. Den kritiske rute vil derfor ændre sig efter effekten af samtidigheden for varmtvandsbehov og det har en væsentlig betydning for driftsforhold.

For at kunne minimere den risiko kan vi dimensionere alle ledninger efter en bestemt trykgradient.

5.5 Referencer

- Beslutninger og aftaler omkring temperaturprofil henvises til lavenergigruppen´s mødereferat ” *L:\Funktioner\Varme\Planlægning og projekt\Lavenergigruppen*”
- Økonomi ” *L:\Funktioner\Varme\Planlægning og projekt\Lavenergigruppen\Økonomi”*
- Varme Ståbi 4. udgave (Nyt teknisk forslag)
- EFP2007-projekt: Udvikling og demonstration af lavtemperaturfjernvarme til lavenergibyggeri.
- Bygningsreglementet 2008 (SBi-anvisning om Bygningsreglementet: *http://www.sbi.dk/br08*)
- SBI-Anvisning 15 – Statens Byggeforskningsinstitut 1990

Appendix 2

Kunders huse sat under lup i Århus

Otte huse er blevet tæt studeret, og kunderne har fået luksus-service af AffaldVarme Århus. Resultaterne har været nedslående, overraskende og lærerige.

OPTIMERING

Af journalist Flemming Linnebjerg Rasmussen, Dansk Fjernvarme

Hvordan står det egentlig til med de huse, der er i den anden ende af fjernvarmeledningen?

Dette, på overfladen, ret simple spørgsmål har været udgangspunktet for et projekt, hvor AffaldVarme Århus har set nærmere på en lille klynge på otte huse.

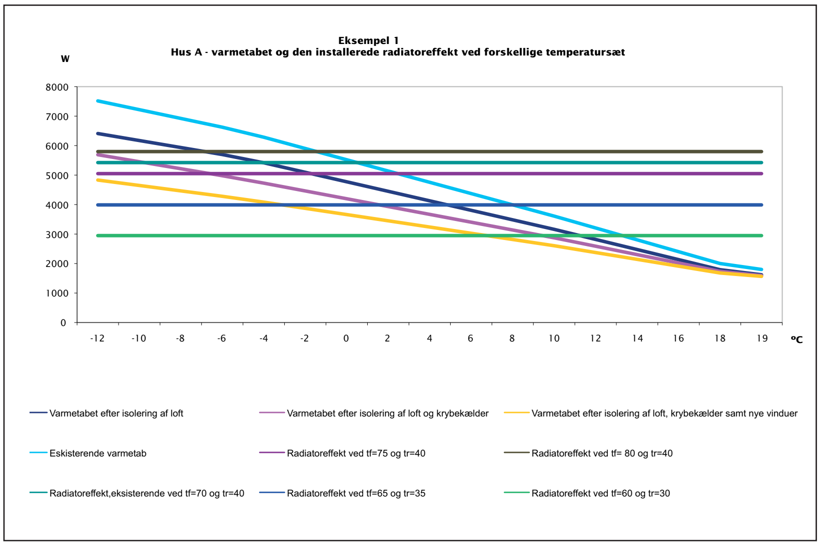
Hvilken stand er radiatorerne i og hvad med husets fjernvarmeunit og isolering? Hvordan har skiftende beboere behandlet huset og varmesystemet gennem årene, og hvordan ser de nuværende ejere på deres hus og de muligheder, der er for at optimere energiudnyttelsen?

Spørgsmål som disse og mange flere er blevet besvaret, og samtidig har AffaldVarme Århus haft en god dialog med beboerne om de tiltag, der kunne forbedre energisystemet i deres bolig.

- Man kan sige, at de har fået den ultimative luksusbehandling: En analyse af hver enkelt bolig kombineret med en grundig dialog. Samtidig har de fået nogle unikke muligheder for tilskud til energirenoveringer. Hvis vi havde ressourcer til det, kunne vi give alle vores kunder dette tilbud, siger Mette Rude, der er funktionsleder i Varme.

Konklusionen efter kigget ind bag facaden hos de otte tilfældige kunder har ikke været opløftende.

- Vi havde ikke forestillet os, at det så helt så slemt ud. I vores tekniske bestemmelser garanterer vi at levere 60 grader varmt vand og ikke mere. Men gennemførte vi det i praksis, ville det gå helt galt. Det kan husene og deres varmesystemer slet ikke klare sig med. Det er faktisk ret tankevækkende, mener Mette Rude.



Eksempel på hus med underdimensionerede radiatorer
De vandrette linjer afspejler radiatorydelsen ved forskellige temperatursæt, mens de "skrå" linjer viser varmetabet nu og efter energiforbedringer. Den installerede radiatoreffekt i huset (TF = 80º C) dækker først det eksisterende varmebehov, når udetemperaturen når op på -1 ˚C.

Hvis loft og krybekælder isoleres, kan varmetabet sænkes, så huset opnår det ønskede varmebehov ved -12 ºC. Dette giver dog stadig ikke mulighed for at sænke fremløbstemperaturen. For at kunne gøre det, skal de foreslåede energiforbedringer suppleres med en større radiatoreffekt.

Typiske 70'er-huse

Husene ligger i bydelen, Tilst, nærmere bestemt i Skjoldhøjparken, som er et af Danmarks største parcelhuskvarterer med huse fra 70´erne. Husene er ret ens og udgør et godt bud på et "standard-hus" fra denne periode. Det gør husene velegnede til en slags stikprøveundersøgelse af, hvordan man kan forestille sig, at en lang række øvrige danske parcelhuse tager sig ud.

Selvom otte tilfældige huse ikke kan udgøre et repræsentativt udsnit, der kan laves egentlig statistik på, giver projektet alligevel interessant viden for AffaldVarme Århus.

Kundens varmebehov er afgørende for anlæg og drift af ledningsnettet. Derfor kan den viden, der er kommet ud af projektet, ifølge Mette Rude være værdifuld, når det handler om at optimere det samlede system.

- Vi ville se på, hvad der egentlig er sket med husene, siden de blev bygget. Hvis vi leger med tanken om, at de er repræsentative, kan vi bedre forholde os til, hvordan vi kan optimere nettet i sådanne boligkvarterer.

Sagt på en anden måde: Det nytter ikke at renovere ledningsnettet til mindre dimensioner og sænke fremløbstemperaturen markant, hvis ikke husene kan klare sig på disse vilkår. Tingene skal følges ad.

- Vi kan ikke gøre det bedre end det svageste led. Hvis vi med energisparetilskud kan ændre på kundens varmebehov, kan vi også ændre vores drift, konstaterer Mette Rude.

Udløb fra Realea-projektet

Hele projektet er en udløber af et andet projekt, udført af Ejendomsselskabet Realea. Her blev fire huse i kvarteret energirenoveret. Det ene blev helt gennemgribende renoveret, mens de øvrige tre fik forskellige dele renoveret. Formålet har været at vise, hvad man kan opnå ved at energirenovere typiske 70´er-huse.

Som fjernvarmeselskab har AffaldVarme Århus været involveret i projektet og så derfor en mulighed for at fortsætte arbejdet i området. Et af de fire huse fra Realea-projektet ligger således placeret i hjørnet af det vænge på otte huse, der udgør AffaldVarme Århus' projekt.

Tålmodighed og dialog

AffaldVarme Århus ville gerne helt ind på livet af de otte huse og deres beboere. Det fortæller trainee, Irisanda Mehmedbasic, der har været den bærende kraft i projektet.

Første skridt var at samle beboerne fra de otte huse til et møde. Her fik de information om, hvilke planer fjernvarmeselskabet havde med projektet.

- Vi lagde meget vægt på, at det i sidste ende var op til dem selv, om de ønskede at bruge penge på at energirenovere. Vi understregede også, at alt det, vi gjorde i forbindelse med projektet, eksempelvis det gratis FjR-eftersyn, ikke ville føre til prisstigninger. Og vi garanterede, at vi ikke ville lave nogen ændringer, der forringede deres vilkår.

- Vi startede med at tilbyde alle beboerne en gratis gennemgang af deres hus via Fjernvarmens Serviceordning. Det sagde alle "ja tak" til. Rapporterne var god basisviden for os, men vi lavede selv en masse ekstra beregninger for at blive klogere på husene, siger hun.

- Undervejs har vi haft gode samtaler med hver enkelt familie. Det krævede tålmodighed og fleksibilitet at få det til at lykkes. Det var meget vigtigt for os, at alle beboerne var med om bord, forklarer Irisanda Mehmedbasic.

For små radiatorer

FjR-rapporterne, suppleret af de ekstra beregninger samt de grundige samtaler, gav Irisanda Mehmedbasic og hendes kolleger mulighed for at danne sig et ret præcist billede af hvert enkelt hus.

- Husene fremstår som sådan pæne og velholdte, og beboerne har da også et klart indtryk af, at der er passet godt på husene i årenes løb, fortæller Irisanda Mehmedbasic.

De faktuelle oplysninger om husenes klimaskærm og energisystemer taler dog deres eget tydelige sprog – det er ikke her ret mange af kræfterne og pengene til vedligeholdelse er brugt. Eksempelvis havde et af de otte huse et et-strenget system, mens et andet havde en meget gammel rørveksler.

- Desuden har vi fået punkteret den myte, at 70´er-huse har store radiatorer. Faktisk har det modsatte vist sig i disse huse. De er underdimensionerede, og nogle steder har folk også fjernet en radiator, eksempelvis i en entré.

Undersøgelsen viser, at kombinationen af en utilstrækkelig klimaskærm og et forældet og underdimensioneret energisystem betyder, at flere huse

(Fortsættes næste side)

(Fortsat fra forrige side)

slet ikke kan varmes ordentligt op. De 60 graders fremløbstemperatur, AffaldVarme Århus garanterer, rækker i hvert fald ikke.

- Flere af husene har brændeovn, som bliver flittigt brugt, og tallene viser, at det faktisk også er nødvendigt, vurderer Irisanda Mehmedbasic.

Alle husene er også blevet termografi-fotograferede. Det har underbygget de øvrige oplysninger.

- Og så har det været meget værdifuldt i forhold til at illustrere over for beboerne, hvordan deres huse ser ud energimæssigt. Her er det vores erfaring, at sådanne fotos virkelig er brugbare.

Konkrete tiltag

Selvom de otte huse viste sig energimæssigt værre end forventet, har AffaldVarme Århus stadig mulighed for at optimere fjernvarmesystemet. Helt konkret sker der to forandringer i den måde, fjernvarmen fremover vil strømme til de otte huse på: En ny blandesløjfe bliver etableret, så temperaturen kan sænkes og reguleres særskilt for de otte huse, og samtidig vil fremløbstemperaturen nu blive ændret flere gange om året.

De otte huse vil blive fulgt tæt for at se, om disse forandringer giver anledning til problemer for beboerne.

- Det, vi gør, er at lægge en ny driftsplan med udgangspunkt i det ringeste af husene. Det er vigtigt, at beboerne ikke mærker forringelser på komforten, understreger Mette Rude.

Yderligere optimeringer må så komme i takt med, at husene forbedres. Derfor er det også en del af projektet at give nogle ekstraordinære tilskudsmuligheder til beboerne i de otte huse. Formålet er at efterprøve, om det kan få folk til at investere i energiforbedringer.

Ud over det ordinære tilskud på 25 øre pr. sparet kWh kan beboerne få et ekstraordinært tilskud, hvis de forbedrer til et niveau, der er højere end dagens standard. Beboerne har et år til at benytte sig af den mulighed.

- Nogen har taget godt imod det tilbud, mens andre tilsyneladende forventede, at vi ville betale meget mere. Nu må tiden vise, hvad det fører med sig, konstaterer Mette Rude.

God inspiration

Ifølge Irisanda Mehmedbasic har beboerne hele vejen igennem været positive over for projektet.

- De har taget fint imod os, og flere har givet udtryk for, at det har været godt at få en indsigt i deres hus, de ellers ikke ville have haft.

Trods husenes lidt sølle, efter dagens standard, energimæssige stand forventer hun dog, at det vil være lidt blandet, om beboerne vil lave energimæssige forbedringer af deres huse. Nogen vil helt sikkert ingenting gøre, nogen vil med garanti gøre noget, mens andre overvejer situationen.

- Økonomien spiller en rolle. Tilbagebetalingstiden på mange forbedringer er lang, og det er en barriere. Vi har derfor også lagt mest vægt på de komfortforbedringer, der kan opnås, siger hun.

Som det næste tiltag i projektet har AffaldVarme Århus inviteret beboerne til et møde. Her vil de blive orienteret om de driftsforandringer, der bliver gjort ved fjernvarmenettet i deres vænge uden at forringe beboernes komfort.

Samtidig har AffaldVarme Århus fået noget at tænke over.

- Projektet har givet os den første inspiration til, hvad vi kan gøre for at optimere andre steder. Det har givet os en masse at tænke over, og det har i det hele taget været meget lærerigt at møde de meget forskellige husejere, der bor i de otte huse, fastslår Mette Rude.

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Appendix 3

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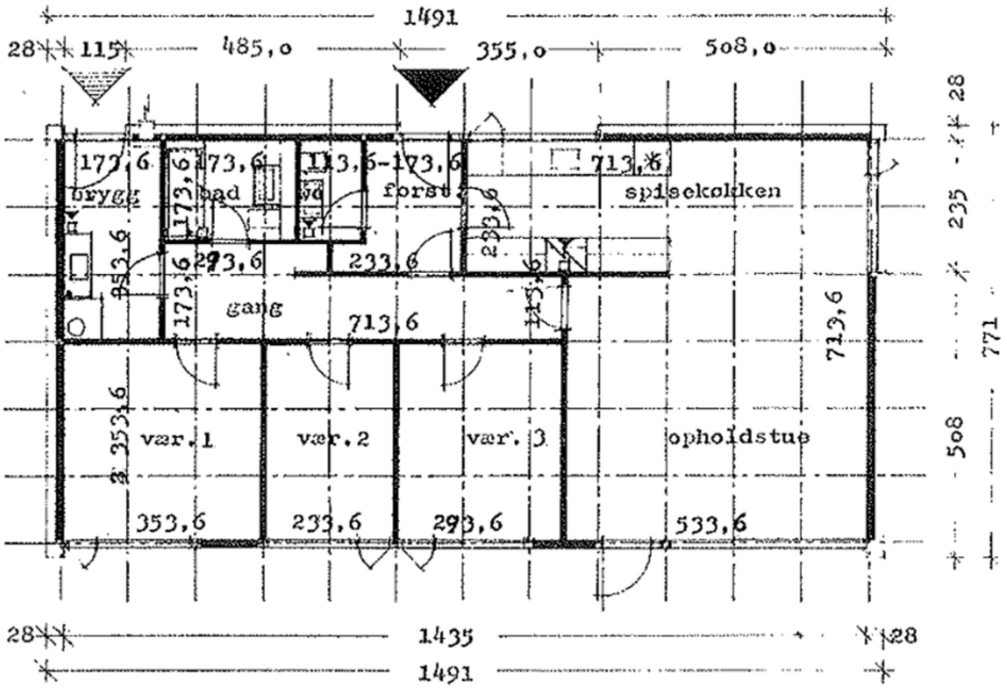
Lavenergifjernvarme til eksisterende byggeri – Langøvænget, Århus

Analyse af radiatoranlæg til eksisterende byggeri

EU har skærpet energikravene til både nye og eksisterende bygninger. Der kan hentes store energibesparelser på parcelhuse opført i 60'erne og 70'erne ved at energirenovere, da omkring halvdelen af Danmarks parcelhuse er opført i denne periode. Af denne grund ses på en minimal renovering af et eksisterende byggeri fra 70'erne. Hensigten er at nedbringe varmetabet og dermed effektbehovet, samt at benytte lavere temperaturer til opvarmning i de eksisterende radiatorer.

Det eksisterende byggeri er et parcelhus fra 1972, med et bebygget areal på 115 m^2 og ligger på Langøvænget i Århus. Plantegningen ses på Figur 1. Husets mål tager udgangspunkt i denne tegning, mens opbygning af konstruktioner mm. er fra tegningen over plan, snit og facader. Huset er i ét plan med et tag der hælder fra midten med 20$^{\mathrm{o}}$. Rumhøjden er 2,39 m, da der er fladt loft i hele huset.



Figur 1 - Plantegning af det eksisterende byggeri.

Husets ydervægskonstruktioner er på 30 cm med 100 mm isolering. Gulvet er isoleret med 90 mm i alle rum. Tag- og loftkontruktionen er udført med 100 mm isolering. Huset opvarmes med radiatorer og der er radiatorer i alle rum på nær i forstuen, bryggers og på wc'et. På badeværelset er der også elektrisk gulvvarme.

U-værdierne for alle yderkonstruktionerne bortset fra vinduerne er i Tabel 1, mens linjetaget for fundamentet er i Tabel 2 - Linjetab for fundament for det eksisterende byggeri.Tabel 2.

Tabel 1 - U-værdier for det eksisterende byggeri.

Konstruktion	U-værdi $[W/m^2K]$
Ydervæg	0,31
Krybekælder	0,42
Gulv, ”stressed”-skin	0,40
Tag	0,33
Yderdør i bryggers og forstue	1,46

Tabel 2 - Linjetab for fundament for det eksisterende byggeri.

Konstruktion	Linjetabet $[W/mK]$
Fundamenter	0,7

Der ses på 3 forskellige scenarier mht. vinduernes U-værdi. Første scenarie har vinduerne en U-værdi på2,8 $\mathrm{W/m^2K}$, anden på 1,4 $\mathrm{W/m^2K}$ og tredje scenarie er med en U-værdi på 0,9 $\mathrm{W/m^2K}$.

Arealet på vinduer og døre i huset er angivet i Tabel 3.

Tabel 3 - Størrelser på vinduer og døre i huset.

Konstruktion	Antal i huset	Størrelse i m^2 [bredde·højde]
Yderdøre	3	1,15·2,2
Vinduer i stuen ved glasdøren	3	1,15·1,6
Vinduer	5	2,00·1,2

Ventilationen estimeres til et luftskifte på 0,5 h^{-1}, og at der er aftrækskanaler i køkken, bad, wc og bryggers.

Der er ikke hverken radiatorer eller gulvvarme i bryggerset, wc’et eller i forstuen, og for at opretholde omkring 20°C hele året i disse rum indsættes en radiatorer magen til den i gangen i forstuen, i bryggerset indsættes en radiator magen til dem i værelserne og på wc’et indsættes en radiator magen til den på badeværelset. Tabel 4 er en oversigt over rummene i huset med de installerede radiatorer samt varmeeffekten ved et temperatursæt på 70/40/20. Der ønskes 22°C på badeværelset, og varmeeffekten fra radiatoren i dette rum er derfor ved temperatursættet 70/40/22.

Tabel 4 - Radiatorer i eksisterende byggeri.

Rum	Antal vinduer/døre	Antal radiatorer	Radiator type	Dimension Højde/længde [m/m]	Varmeeffekt pr. radiator [W]
Bad	0	1	1P	300/1000	165
Bryggers	1 dør	1	2P	650/2200	858
Forstue	1 dør	1	2P	550/580	285
Gang	0	1	2P	550/580	285
Stue/køkken	1 dør, 3 vinduer ved	1	2P	550/1900	1.254

	døren og 2 alm. vinduer				
Stue/køkken	1 dør, 3 vinduer ved døren og 2 alm. Vinduer	1	3P	300/3400	1.530
Værelse 1	1 alm. Vindue	1	1P	650/2200	858
Værelse 2	1 alm. Vindue	1	1P	650/2200	858
Værelse 3	1 alm. Vindue	1	1P	650/2200	858
WC	0	1	1P	300/1000	180

Den åbne stue/køkken indeholder en brændeovn. Denne brændeovn modelleres dog ikke i BSim.

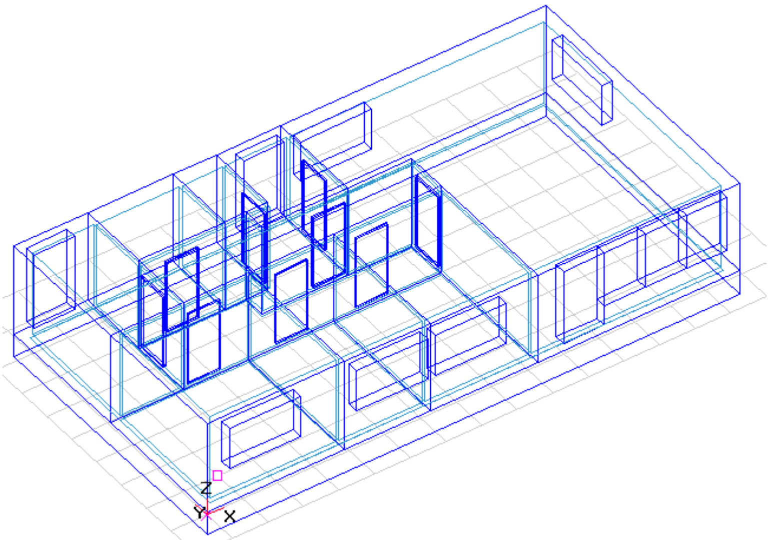
Varmeeffekterne er fra besigtigelsesrapporten. Disse varmeydelserne ved temperatursættet 70/40/20 omregnes til forskellige fremløbs- og returløbstemperaturer.

For at opnå detaljerede beregninger omkring husets energiforbrug og indeklima, modelleres huset i simuleringsprogrammet BSim. BSim regner med dynamiske modeller, og husets beliggenhed fastsættes til København, hvormed der regnes med danske vejrdata. BSim efterligner kort sagt virkeligheden.

I BSim undersøges det om husets radiatorer kan levere nok varme ved lave temperaturer til, at opretholde det ønskede indeklima.

Simulering i BSim

Huset blev modelleret i BSim og modellen ses på Figur 2



Figur 2 - BSim-modellen af det eksisterende byggeri.

Huset består af 9 rum. Som nævnt tidligere benyttes vejrdata for København, og heri bruges data fra det danske design reference år. Bygningen har glaspartiet i stuen og vinduerne i værelse 1 til 3 vendt mod syd, og er afgrænset af ydervægge, krybekælder, tag, vinduer, døre og fundament. Fundament og krybekælder er vendt mod jord med en temperatur på 10°C.

Systemer

Bygningsmodellen er opdelt i 9 zoner, som svarer til én zone pr. rum. Zonerne bruges til at tilføje udstyr, mennesker, varmeapparat mm til rummene. Disse komponenter indsættes i modellen i form af systemer. Systemerne indeholder en tidsplan, der angiver brugen og effekten af systemet.

Opvarmning

Huset opvarmes ved brug af radiatorer og elektrisk gulvvarme i ét rum. Den maksimale effekt af opvarmningsanlægget sættes til effekten af den/de pågældende radiatorer i rummet. Der opvarmes kun i opvarmningssæsonen, fra september til maj, hvor begge måneder er inkluderet. Det antages at 70 % af radiatorernes varmeafgivelse tilføres indeluften ved konvektion. De resterende 30 % sker ved stråling til zonens overflader. For at holde den operative temperatur i rummene over 20°C (22°C for badeværelset) sættes setpointet i BSim til en halv grad højere. Dette er baseret på tidligere erfaring med programmet.

Da den maksimale effekt af opvarmningsanlægget netop er lig med den effekt jeg har udregnet for den pågældende radiator ved det ønskede temperatursæt, simulerer BSim med en flowbegrænser, og dermed er besvarelserne til Task 3.2 og 3.3 slået sammen til én.

Intern varmebelastning

Den interne varmebelastning i huset består af varmetilskuddet fra eludstyr, belysning og personer. Der benyttes en intern varmebelastning på 5 $\mathrm{W/m^2}$ i alle rum.

Ventilation

Der estimeres at der er naturlig ventilation i huset via aftrækskanaler, i bad, bryggers, stue/køkken og wc, samt åbning af døre og vinduer i alle rum hvor disse forekommer. Grundet utætheder omkring vinduer og døre i klimaskærmen opstår infiltration, og den naturlige ventilation og infiltrationen modelleres som én i BSim til et luftskifte på 0,5 $\mathrm{h^{-1}}$ i alle rum.

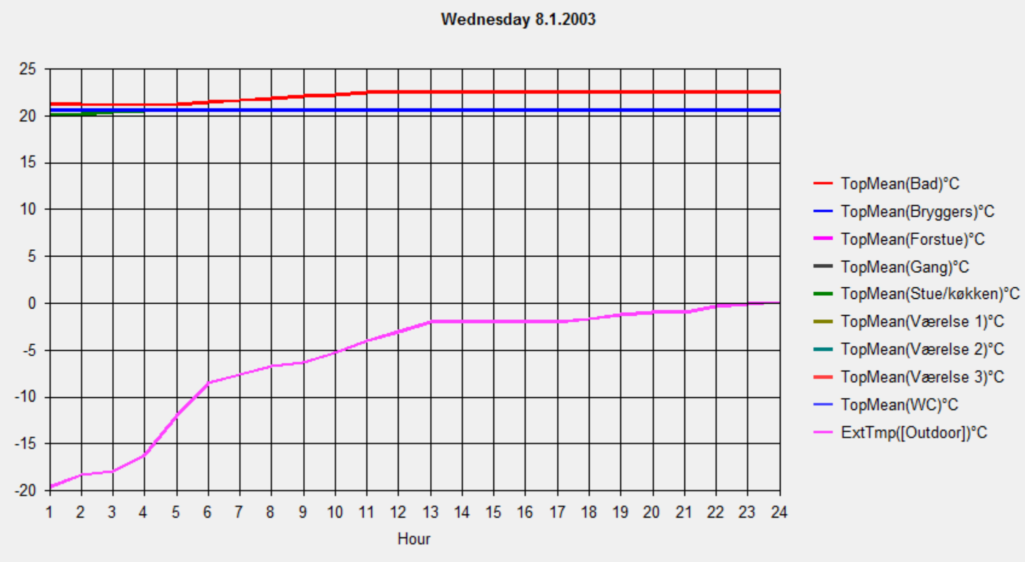
Resultater ved BSim simulering

Der simuleres for perioden 1. januar 2003 til 31. maj 2003 og 1. september 2003 til 31. december 2003, da dette er opvarmningssæsonen.

Case 1

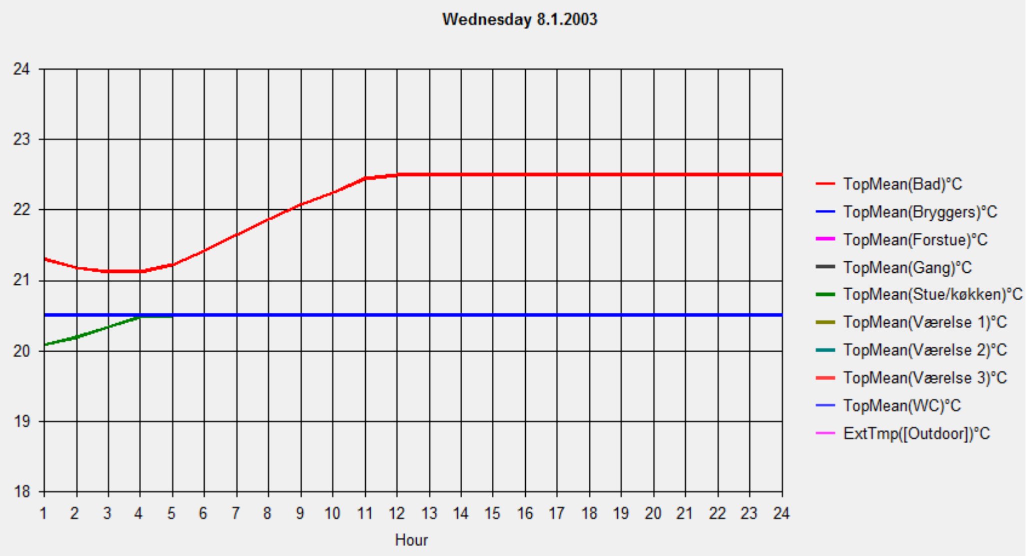
I case 1 er U-værdien af vinduerne 2,5 $\mathrm{W/m^2K}$ og g-værdien 0,43.

I simuleringsperioden med en fremløbstemperatur på 70°C og en returløbstemperatur på 40°C, er der ingen rum der er under 20°C, se Figur 3. Der ses på onsdag d. 8.1.2003, da de operative temperaturer er lavest denne dag.



Figur 3 – Operativ temperaturvariation for case 1 d. 08.01.03 ved 70/40.

Badeværelset falder til under 22°C i nogle timer onsdag d. 8.1.2003, men da der også er elektrisk gulvvarme på badeværelset, som ikke er implementeret i BSim-modellen, antages det er badeværelset godt kan holde sig på den ønskede operative temperatur hvis denne var slået til. På Figur 4 ses et udsnit af Figur 3, og her ses det tydeligt at den operative temperatur på badeværelset faldet, men også at den operative temperatur i stuen/køkkenet falder en smule, men ikke kommer under 20°C.



Figur 4 - Udsnit af figur 3.

Der ses nu på nogle lavere temperatursæt i de eksisterende radiatorer. I **Error! Reference source not found.** ses hvilken udetemperatur de forskellige fremløbs- og returløbstemperaturer kan klare, når der skal opretholdes 20°C i alle rum, når der ses bort fra badeværelset

Tabel 5 – Udetemperaturer ved forskellige temperatursæt for case 1.

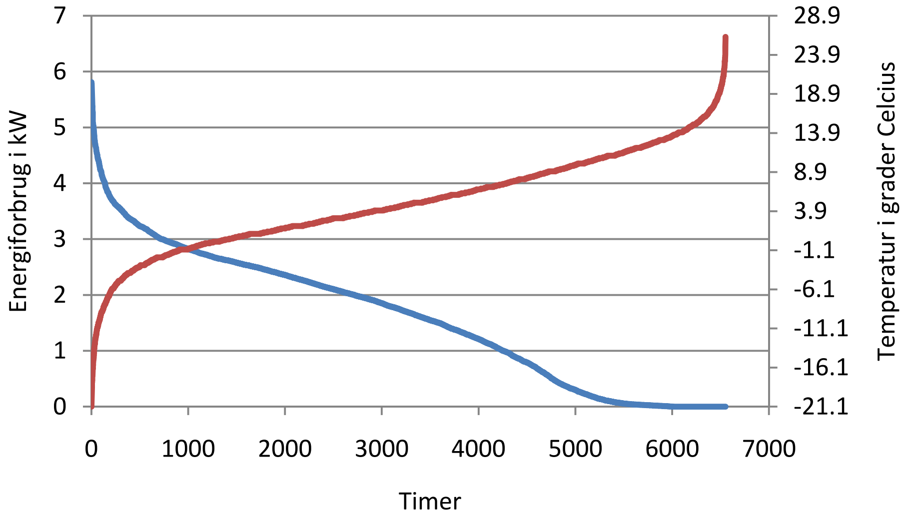
Temperatursæt	Udetemperatur som temperatursættet kan "klare"
60/28/20	+1°C
60/30/20	-2°C
65/30/20	-3°C
65/35/20	-6°C
70/35/20	-8°C
70/40/20	-21°C

Ovenstående tabel skal forstås på følgende måde: Temperatursættet 60/28/20 kan opretholde 20°C i alle rum, på nær badeværelset, når udetemperaturen er 1°C eller højere. Hvis udetemperaturen falder til -2°C, er det nødvendigt at benytte temperatursættet 60/30/20, for at opretholde 20°C i alle rum på nær badeværelset. Grunden til at der ses bort fra badeværelset er, fordi der ønskes en operativ temperatur på 22°C derinde, og derudover indeholder badeværelset elektrisk gulvvarme, som ikke er med i BSim-modellen. Det antages, at der godt kan opnås en operativ temperatur på 22°C derinde med lave temperaturer i radiatoren når gulvvarmen en tændt. Det koldeste rum er til en hvert tid stuen/køkkenet.

Det bemærkes, at den maksimale udetemperatur går fra -21°C til -8°C på ved blot at ændre returløbstemperaturen med 5 grader, fra 40°C til 35°C. Dette skyldes, at udetemperatuen stiger hurtigt d. 08.01.03, som kan ses på **Error! Reference source not found.**.

Effektbehov for case 1

Effektbehovet i Figur 5 er det totale behov for huset fra september til maj til opvarmning. Det er rangeret fra højeste totale behov til laveste som er den blå kurve, mens den røde kurve er udetemperaturen fra laveste til højeste. Det ses at det maksimale effektbehov til opvarmning er på 5,8 kW for hele huset.



Figur 5 - Effektbehov til opvarmning for case 1.

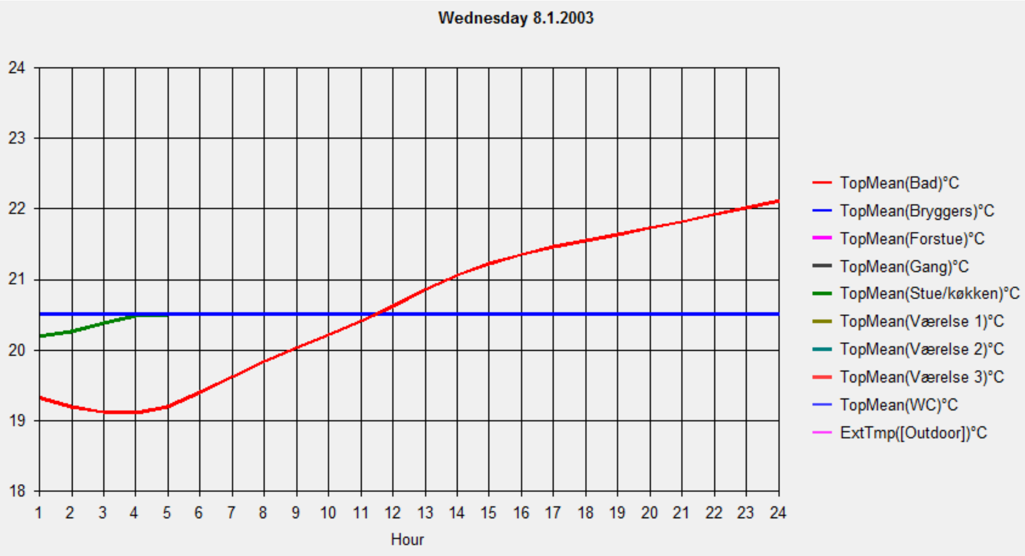
Energiforbruget i opvarmningssæsonen for case 1 er 10.490 kWh.

Der undersøges dernæst hvor meget temperatursættet og effektbehovet kan sænkes ved at sætte bedre vinduer i huset.

Case 2

I case 2 er U-værdien af vinduerne 1,4 $\mathrm{W/m^2K}$ og g-værdien 0,43.

Der simuleres med 65/35 og i simuleringsperioden er der ingen rum der er under 20°C, se Figur 6, bortset fra badeværelset.



Figur 6 – Operativ temperaturvariation for case 2 d. 08.01.03 ved 65/35.

Der ses igen på onsdag d. 8.1.2003, da de operative temperaturer er lavest denne dag. Badeværelset falder til under 22°C næsten hele dagen, men da der også er elektrisk gulvvarme på badeværelset, som ikke er implementeret i BSim-modellen, antages det er badeværelset godt kan holde sig på den ønskede operative temperatur hvis denne var slået til.

Der ses dernæst på lavere temperatursæt i de eksisterende radiatorer, Tabel 6.

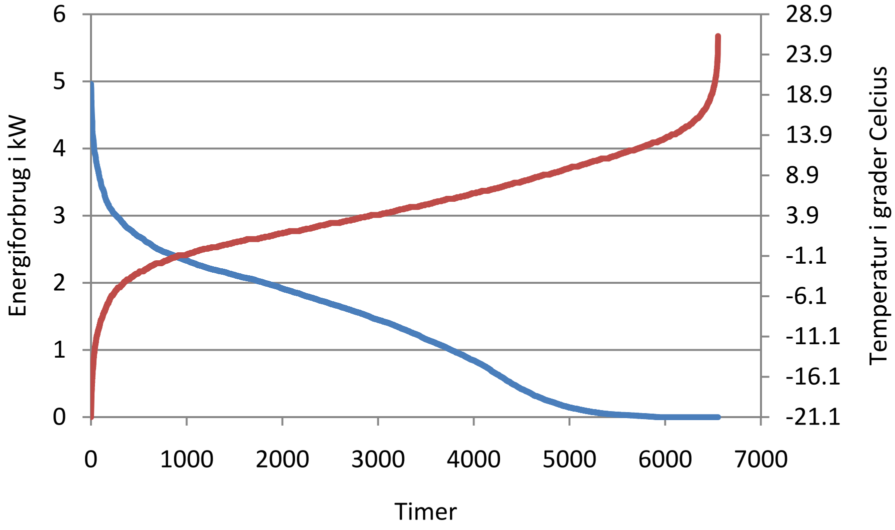
Tabel 6 - Udetemperaturer ved forskellige temperatursæt for case 2.

Temperatursæt	Udetemperatur som temperatursættet kan "klare"
60/25/20	+1°C
60/28/20	-2°C
60/30/20	-4°C
65/30/20	-7°C
65/33/20	-12°C
65/35/20	-21°C
70/35/20	-21°C
70/40/20	-21°C

Temperatursættet 60/28/20 kan opretholde 20°C i alle rum, når udetemperaturen er -2°C eller højere. Hvis dette resultat sammenlignes med case 1, kunne dette temperatursæt før kun klare udetemperaturer ned til +1°C.
Hvis temperatursættet 70/35/20 for case 1 og 2 sammenlignes, ses det at case 2 kan klare ned til -21°C med dette temperatursæt, mens case 2 kun kan klare -8°C.

Effektbehov for case 2

Effektbehovet i Figur 5 er det totale behov for huset fra september til maj til opvarmning. Det totale behov er den blå kurve, mens den røde kurve er udetemperaturen. Det ses at det maksimale effektbehov til opvarmning er på 5,0 kW for hele huset.



Figur 7 - Effektbehov til opvarmning for case 2.

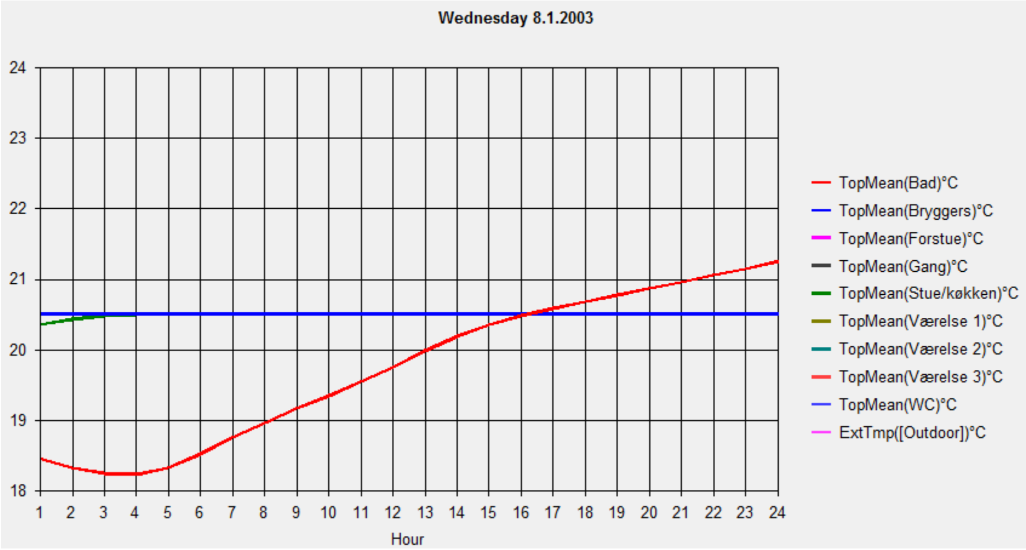
Energiforbruget for case 2 i perioden 1. januar 2003 til 31. maj 2003 og 1. september 2003 til 31. december 2003 er på 8.299 kWh.

Der undersøges slutteligt hvor meget temperatursættet og effektbehovet kan sænkes yderligere ved at sætte endnu bedre vinduer i huset.

Case 3

I case 3 er U-værdien af vinduerne 0,9 $\mathrm{W/m^2K}$ og g-værdien 0,35.

I simuleringsperioden med en fremløbstemperatur på 65°C og en returløbstemperatur på 32°C, er der ingen rum der er under 20°C, se Figur 8, bortset fra badeværelset.



Figur 8 - Operativ temperaturvariation for case 3 d. 08.01.03 ved 65/32.

Endnu engang falder den operative temperatur på badeværelset til under 22°C, og endnu en gang ses der bort fra dette.

Igen blev mulighederne for at benytte lavere frem- og returløbstemperaturer undersøgt. Det koldeste rum blev nu forstuen, og dette skyldes at U-værdien af hoveddøren ikke blev bedre når vinduerne blev udskiftet. Men da dette rum ikke indeholdt en radiator til at starte med og derfor fik en radiator magen til den på gangen, indsættes derfor en anden radiator i forstuen magen til den i bryggerset. Resultat af simuleringerne med ny radiator i forstuen og nye vinduer kan ses i Tabel 7.

Tabel 7 - Udetemperaturer ved forskellige temperatursæt for case 3.

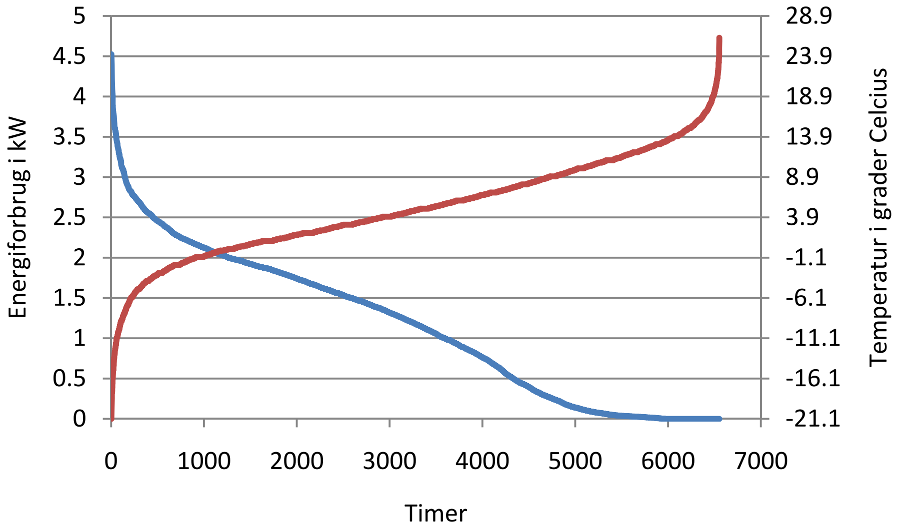
Temperatursæt	Udetemperatur som temperatursættet kan ”klare”
52/25/20	0°C
55/25/20	-1°C
60/25/20	-2°C
60/28/20	-4°C
60/30/20	-7°C
65/30/20	-12°C
65/31/20	-17°C
65/32/20	-21°C
65/35/20	-21°C
70/40/20	-21°C

Temperatursættet 60/28/20 kan opretholde 20°C i alle rum, når udetemperaturen er -4°C eller højere. Hvis dette resultat sammenlignes med case 1, kunne dette temperatursæt før kun klare udetemperaturer ned til +1°C, og case 2 kunne ved samme temperatursæt klare ned til -2°C.

Når det er 0°C udenfor kan temperatursættet komme helt ned på 52/25/20, hvilket er en stor forbedring i forhold til case 1, hvor temperatursættet ved samme udetemperatur var 60/29/20.

Effektbehov for case 3

Effektbehovet i Figur 9 er det totale effektbehov for huset fra september til maj til opvarmning. Det ses at det maksimale effektbehov til opvarmning er på 4,5 kW for hele huset.



Figur 9 – Effektbehov til opvarmning for case 3.

Energiforbruget for case 3 i opvarmningssæsonen er på 7.554 kWh.

Konklusion

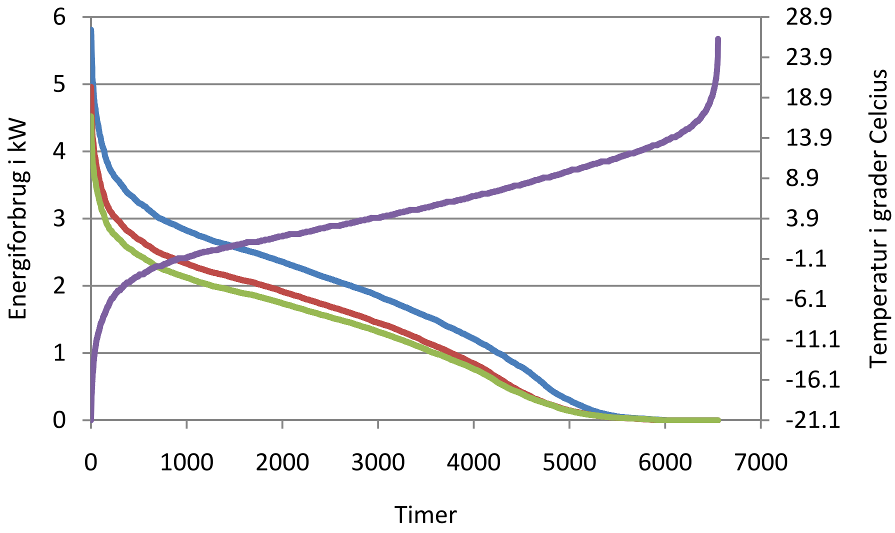
Af ovenstående simuleringer og analyser ses det at, ved at optimere vinduerne kan frem- og returløbstemperaturerne sænkes betydeligt. Dette illustrer Tabel 8.

Tabel 8 - Udetemperaturer ved 60/28/20 for case 1,2 og 3.

Case	Temperatursæt	Udetemperatur som temperatursættet kan "klare"
1	60/28/20	+1°C
2	60/28/20	-2°C
3	60/28/20	-4°C

Vinduerne i case 1 havde en U-værdi på 2,5 $\mathrm{W/m^2K}$ og g-værdi på 0,43, mens case 3 havde 0,9 $\mathrm{W/m^2K}$ og 0,35 og en større radiator i forstuen. Disse ændringer gør at frem- og returløbstemperaturerne 60°C og 28°C hhv. kan "klare" 5°C koldere udetemperaturer.

Figur 10 illustrerer de 3 forskellige effektbehov for case 1, 2 og 3 og udetemperaturer for simuleringsperioden. Den lilla kurve er udetemperaturerne, den blå er effektbehovet for case 1, den røde er for case 2 og den grønne er for case 3.



Figur 10 - Effektbehov for case 1, 2 og 3.

Det ses af ovenstående figur, at når klimaskærmen optimeres sænkes effektbehovet til opvarmning, hvilket det naturligvis også skal, da varmetabet fra huset sænkes ved optimeringen.

Ved at udskifte vinduerne kan det maksimale effektbehov til opvarmning sænkes med 1,3 kW. De maksimale effektbehov og egenskaber for vinduerne for de tre scenarier er præsenteret i Tabel 9.

Tabel 9 - Maksimale effektbehov, energiforbrug, temperatursæt og egenskaber for case 1, 2 og 3.

Case	Egenskaber for vinduerne	Energiforbrug i MWh	Maksimale effektbehov i kW	Nødvendig temperatursæt i radiatorerne ved: $t_{ude} = -21°\mathrm{C}$	$t_{ude} = 0°\mathrm{C}$
1	U-værdi: 2,5 $\mathrm{W/m^2K}$ g-værdi: 0,43	10.49	5,8	70/40/20	60/29/20
2	U-værdi: 1,4 $\mathrm{W/m^2K}$ g-værdi: 0,43	8.3	5,0	65/35/20	60/26/20
3	U-værdi: 0,9 $\mathrm{W/m^2K}$ g-værdi: 0,35	7.55	4,5	65/32/20	52/25/20

Det ses at energiforbruget kan sænkes med 2.936 kWh ved at udskifte vinduerne fra case 1 med dem fra case 3. Derudover kan temperatursættet ved forskellige udetemperaturer sænkes total med 12-13°C. Dette er en klar forbedring og medfører at lavtemperaturer kan benyttes i de eksisterende radiatorer.

Appendix 4

Mette Veith Schroeder 10.09.10 Svend Svendsen

s062963 DTU

Lavenergifjernvarme til eksisterende byggeri – Næstved

Forord

Denne rapport er en kort udgave af bachelorprojektet Rumvarmealæg med lave vandtemperaturer af Mette Veith Schroeder. Projektet er skrevet på Danmarks Tekniske Universitet på instituttet for Byggeri og anlæg d. 14. juni 2010. Vejlederne på projektet var Professor Svend Svendsen og Ph.d. studerende Marek Brand.

Sammenfatning

Formålet med projektet var at udvikle og undersøge gulvvarme- og radiatoranlæg i eksisterende byggeri.

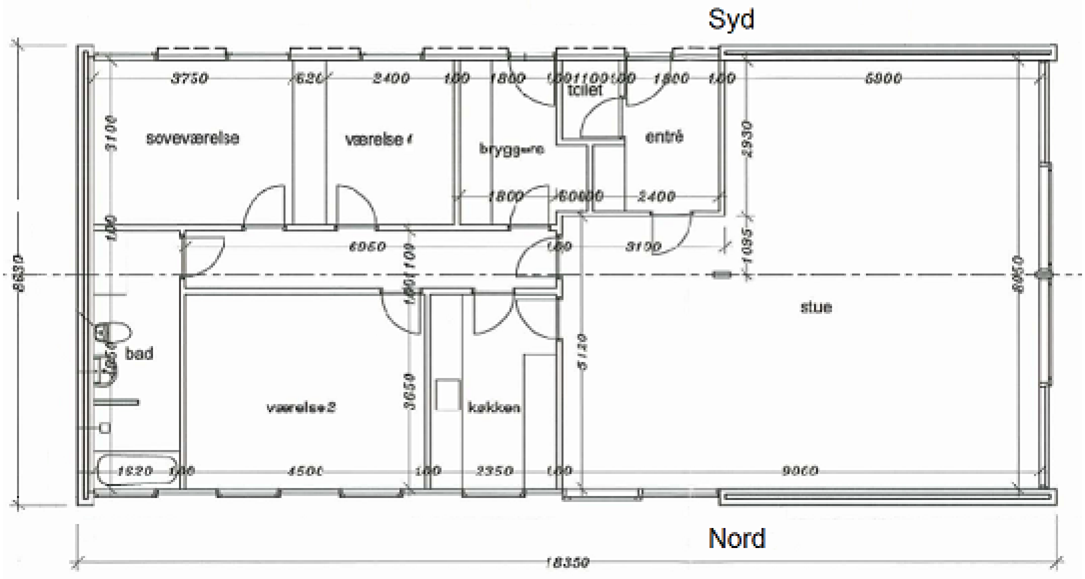
Der blev taget udgangspunkt i et enfamiliehus fra 1970'erne opvarmet med fjernvarme. Ved simuleringer i BSim blev det undersøgt om det var muligt at sænke frem- og returløbstemperaturerne, ved et ønsket indeklima på 20 °C. For at dette kunne lade sig gøre, blev klimaskærmen optimeret ved først at udskifte glasset i vinduer og døre, derefter at udskifte vinduer og døre med energivinduer og slutteligt yderligere udskifte radiatorerne i de mest kritiske rum. Ved alle analyserne var det ønsket at opnå en så lav returløbstemperatur som mulig.

Det var ikke muligt at anvende lavtemperaturer i et eksisterende byggeri og opnå det ønskede indeklima i vintermånederne, uden at hæve fremløbstemperaturen når det bliver minusgrader udenfor. Ved at udskifte de eksisterende vinduer og døre med 3-lags energivinduer, kunne temperatursættet 49/33/20 benyttes når udetemperaturerne var over 0 °C. Ved yderligere at udskifte de kritiske radiatorer, kunne dette temperatursæt benyttes når udetemperaturen kom helt ned på -7 °C. Ved lavere udetemperaturer var det nødvendigt at hæve fremløbstemperaturen for stadig at kunne benytte samme returløbstemperatur på 33 °C.

Analyse af radiatoranlæg til eksisterende byggeri

EU har skærpet energikravene til både nye og eksisterende bygninger. Der kan hentes store energibesparelser på parcelhuse opført i 60'erne og 70'erne ved at energirenovere, da omkring halvdelen af Danmarks parcelhuse er opført i denne periode. Af denne grund ses på en minimal renovering af et eksisterende byggeri fra 70'erne. Hensigten er at nedbringe varmetabet og dermed energibehovet, samt at benytte lavere temperaturer til opvarmning i de eksisterende radiatorer. Analyserne af huset baseres på korrekt dimensionerede radiatorer. Disse dimensioneres ud fra varmetabsberegninger i henhold til DS 418.

Det eksisterende byggeri er et arkitekttegnet parcelhus fra 1972, der er beboet af et ægtepar og en teenager. Plantegningen ses på Figur 1. Husets mål, opbygning af konstruktioner mm. tager udgangspunkt i Rapport R-165 fra DTU Institut for Byggeri og Anlæg. Huset er i ét plan og har et opvarmet etageareal på 143 m^2. Den ene halvdel af huset (stuen) har loft til kip, mens den anden halvdel af huset har traditionelt vandret loft. Rumhøjden er 2,40 m ved vandret loft og maksimalt 4,2 m ved kip. Husets samlede rumvolumen er på 395 m^3.



Figur 1 - Plantegning af det eksisterende byggeri.

Husets ydervægskonstruktioner består dels af tunge ydervægspartier på 30 cm med 75 mm isolering og lette ydervægge udført i træskelet med 100 mm isolering. Terrændækket var isoleret med 30 mm i alle rum, mens det i badeværelset og på toilettet var isoleret med 50 mm. Tag- og loftkontruktionen var udført med 100 mm isolering. Vinduerne var standard 2-lags termoruder i træramme. Huset opvarmes med radiatorer.

Først bliver det dimensionerede varmetab for byggeriet bestemt og derudfra dimensioneres de eksisterende radiatorer. U-værdierne for alle yderkonstruktionerne er illustreret i Tabel 1.

Tabel 1 - U-værdier for det eksisterende byggeri.

Konstruktion	U-værdi $[W/m^2K]$
Tung ydervæg, tegl	0,48
Tung ydervæg, porebeton	0,38
Let ydervæg	0,40
Terrændæk	0,36
Terrændæk, bad og toilet	0,32
Loft, plant	0,36
Skråt tag	0,41
Yderdøre	2,69
Vinduer, værelser og bad	2,74
Vinduer, køkken	2,78
Glasparti, stue N	2,75
Glasparti, stue V, nedre del	2,83
Glasparti, stue v, øvre del	2,89

Ventilationen er baseret på en måling af klimaskærmens lufttæthed, og luftskiftet er fundet til 0,5 h^{-1}. Der er aftrækskanaler i køkken, bad, toilet og bryggers, og derfor er ventilationstabet i disse rum nul. Transmissionstabet, ventilationstabet og det dimensionerede varmetab for hvert rum ses i Tabel 2.

Tabel 2 - Eksisterende byggeris dimensionerede varmetab.

	Transmissions tab	Ventilations tab	Dimensionerede varmetab
Bad	649	0	649
Bryggers	366	0	366
Entre	354	190	544
Gang	128	0	128
Køkken	405	0	405
Soveværelse	953	414	1.366
Stue	5.124	1.929	7.054
Toilet	106	0	106
Værelse1	406	232	638
Værelse2	816	512	1.327
Samlet	9.306	3.277	**12.583**

Det dimensionerede varmetab fra stuen udgør lidt over halvdelen af det samlede varmetab. Dette skyldes bl.a., at stuen udgør 55 % af det samlede ventilationstabet. Ydermere består én af væggene i stuen af en fuld glasfacade og en anden væg indeholder en skydedør på ca. 6 m^2, som medfører et højt transmissionstab fra stuen. Dog noteres det, at varmetilskuddet fra solen, der opstår gennem de store glaspartier, ikke er medregnet ved udregning af det dimensionerede varmetab.

Ud fra det dimensionerede varmetab fra hvert rum, kan radiatorerne i huset bestemmes. Dette gøres for at undgå tilfældigheder som grundlag for analysen. I den periode hvor huset er opført, blev radiatorer ofte overdimensioneret for at være på den sikre side. Dette ønskes ikke i dimensioneringen af radiatorerne, dog kan en mindre overdimensionering ikke undgås, da varmeydelsen af radiatorerne skal være højere end det dimensionerede varmetab.

Det vurderes hvor mange radiatorer der bør være i hvert rum, og dertil fordeles det dimensionerede varmetab på antallet af radiatorerne i det pågældende rum. Herefter vælges en radiator hvis varmeydelse modsvarer varmetabet.

Radiatorerne antages, at have været 2P-radiatorer, som er 2 plade radiatorer, hvilket er typisk for bygninger opført i perioden 1960-1980. I de rum hvor der er vinduer, placeres radiatorerne under vinduet, og har samme bredde som vinduet, for at mindske nedfaldet der opstår ved kolde flader. Badet, køkkenet og de tre værelser har vinduer med en bredde på 1200 mm. Radiatoren i badeværelset er dog ikke placeret under vinduet, da der er et badekar under vinduet. Derfor placeres radiatoren på væggen mod værelse 2.

I bryggerset og entréen er der yderdøre, og her placeres radiatorerne ved siden af døren. Ligeledes placeres radiatorerne i stuen på væggene nær vinduerne. I tabel ses en oversigt over rummene indeholdende antallet af vinduer og yderdøre i hvert rum, antallet af radiatorer, dimensionerne på de valgte radiatorer samt den varmeydelse hver radiator leverer.

Tabel 3 - Radiatorer i eksisterende byggeri.

Rum	Antal vinduer/døre	Antal radiatorer	Dimension Højde/længde [m/m]	Varmeeffekt pr. radiator [W]
Bad	1	1	455/1100	651
Bryggers	1	1	555/600	426
Entré	1	1	455/1000	592
Gang	0	1	255/400	142
Køkken	1	1	255/1200	425
Soveværelse	2	2	455/1200	710
Stue	1 skydedør og glasfacade	4	955/1600	1817
Toilet	0	1	355/300	106
Værelse 1	1	1	455/1200	710
Værelse 2	2	2	455/1200	710

Fra R-165 vides det, at radiatorerne har en fremløbstemperatur på 80 °C og en returløbstemperatur på 40 °C. Radiatorerne blev dimensioneret ud fra RIOpanels regneark. Denne udregner varmeydelsen pr radiatorstørrelse ved et bestemt temperatursæt. Der ønskes en operativ temperatur på 20 °C hele året. En fremløbs-,returløbs- og indetemperaturen som ovenfor beskrives i det følgende som temperatursættet 80/40/20.

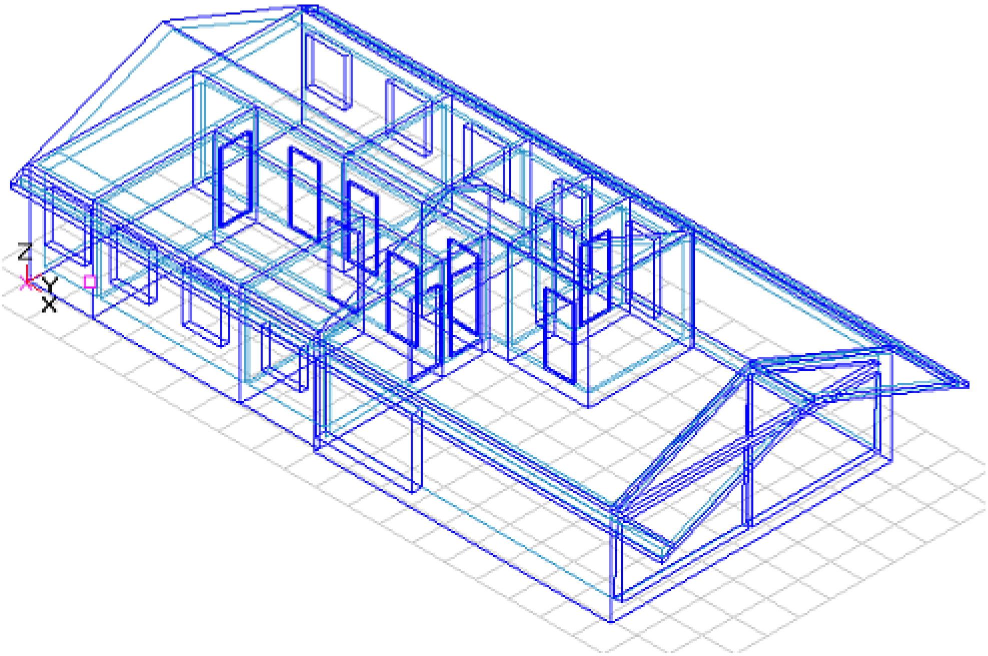
Det bemærkes, at varmeeffekten af radiatorerne i nogle af rummene er en del højere end nødvendigt, hvilket skyldes at disse har en fastlagt længde på 1200 mm. Radiatorerne har i gennemsnit en overdimensionering på 4 %.

For at opnå detaljerede beregninger omkring husets energiforbrug og indeklima, modelleres huset i simuleringsprogrammet BSim. BSim regner med dynamiske modeller, og husets beliggenhed fastsættes til København, hvormed der regnes med danske vejrdata. BSim efterligner kort sagt virkeligheden, og giver mere 'faktiske' beregninger vedrørende huset end beregninger udført i henhold til DS 418.

I BSim undersøges det om husets radiatorer kan levere nok varme ved lave temperaturer til, at opretholde det ønskede indeklima.

Simulering i BSim

Huset blev modelleret i BSim og modellen ses på Figur 2



Figur 2 - BSim-modellen af det eksisterende byggeri.

Huset består af 10 rum. Som nævnt tidligere benyttes vejrdata for København, og heri bruges data fra det danske design reference år. Bygningen har glaspartiet vendt mod vest, og er afgrænset af ydervægge, gulv, tag, vinduer og døre, og terrændækket er vendt mod jord med en temperatur på 10 grader.

Systemer

Bygningsmodellen er opdelt i 10 zoner, som svarer til én zone pr. rum. Zonerne bruges til at tilføje udstyr, mennesker, varmeapparat mm til rummene. Disse komponenter indsættes i modellen i form af systemer. Systemerne indeholder en tidsplan, der angiver brugen og effekten af systemet.

Opvarmning

Huset opvarmes ved brug af radiatorer. Den maksimale effekt af opvarmningsanlægget sættes til effekten af den/de pågældende radiatorer i rummet. Der opvarmes kun i opvarmningssæsonen, fra september til maj, hvor begge måneder er inkluderet. Det antages at 70 % af radiatorernes varmeafgivelse tilføres indeluften ved konvektion. De resterende 30 % sker ved stråling til zonens overflader.

Da den maksimale effekt af opvarmningsanlægget netop er lig med den effekt RIO-panel har udregnet for den pågældende radiator ved det ønskede temperatursæt, simulerer BSim med en flowbegrænser, og dermed er besvarelserne til Task 3.2 og 3.3 slået sammen til én.

Intern varmebelastning

Den interne varmebelastning i huset består af varmetilskuddet fra eludstyr, belysning og personer.

Der er eludstyr i køkkenet, bryggerset og stuen. Køkkenet er det rum med mest udstyr og dette består af emhætte, opvaskemaskine, komfur og køleskab. Fra rapporten Måling af bruttoenergiforbrug i nybyggeri svarende til BR2005 energikrav Byggesystem: Lette ydervægselementer i stålskelet, 2004, DTU Byg af Henrik Tommerup blev effekten og brugstiden af udstyret i huset bestemt. Også fra denne rapport blev effekten af belysningen i huset bestemt.

Der bor 3 personer i huset; et ægtepar og én teenager. Soveværelset er parrets rum, mens værelse 2 er teenagerens. Brugstiden af de forskellige lokaler i huset samt brugerens aktivitetsniveau er estimeret ud fra egne vaner.

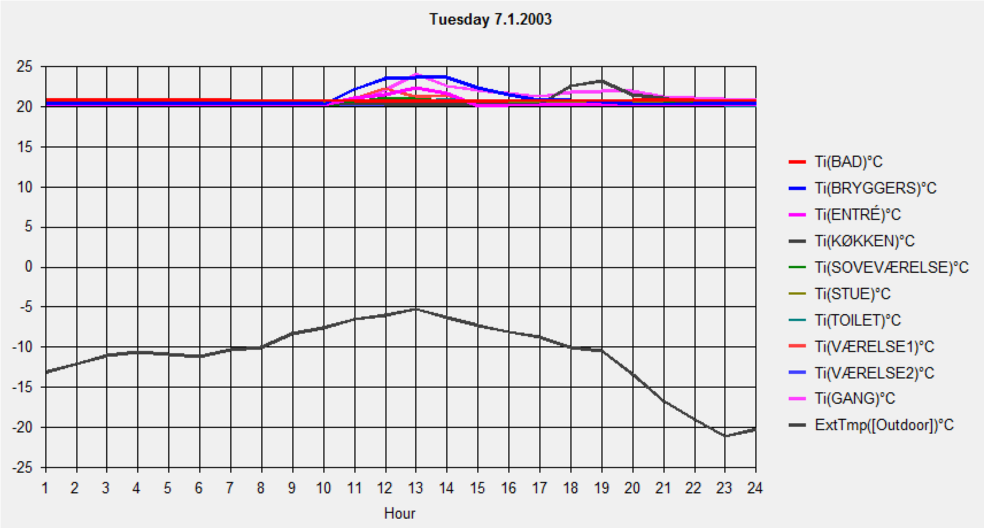
Det antages at brugerne forlader huset alle ugens dage mellem 08-16. Dette er ikke realistisk, men det værste tilfælde undersøges.

Ventilation

Der er naturlig ventilation i huset via aftrækskanaler, i udvalgte rum, samt åbning af døre og vinduer. Grundet utætheder omkring vinduer og døre i klimaskærmen opstår infiltration, og den naturlige ventilation og infiltrationen modelleres som én i BSim.

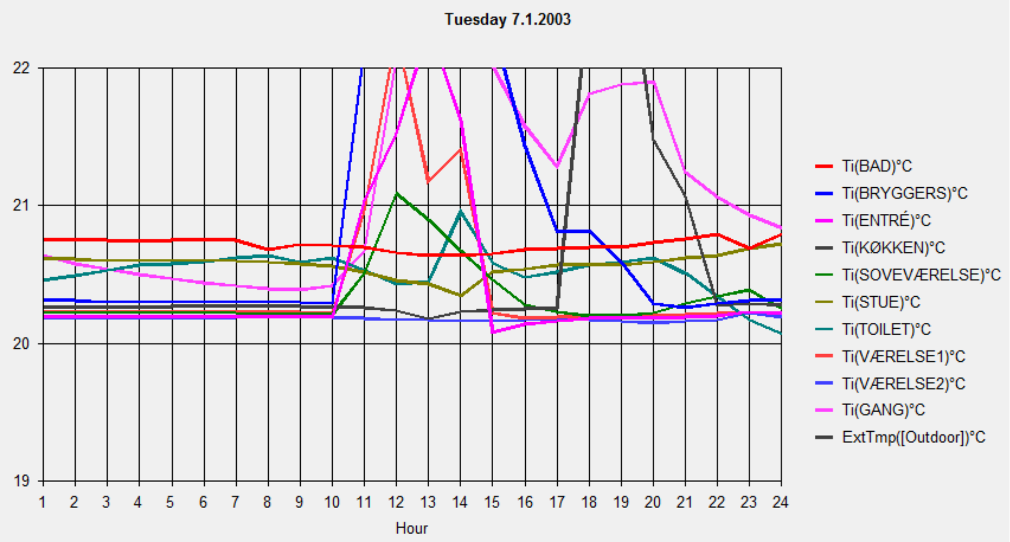
Resultater ved BSim simulering

Der simuleres for perioden 1. januar 2003 til 31. maj 2003 og 1. september 2003 til 31. december 2003, da dette er opvarmningssæsonen. I perioden var der ingen rum der var lavere 20 °C hele simuleringsperioden.



Figur 3 - 80/40/20.

På Figur 4 ses et udsnit af Figur 3.



Figur 4 - 80/40/20 udsnit.

Effekten af en udskiftning af vinduer og døre undersøges i det følgende.

Udskiftning af glas i vinduer og døre

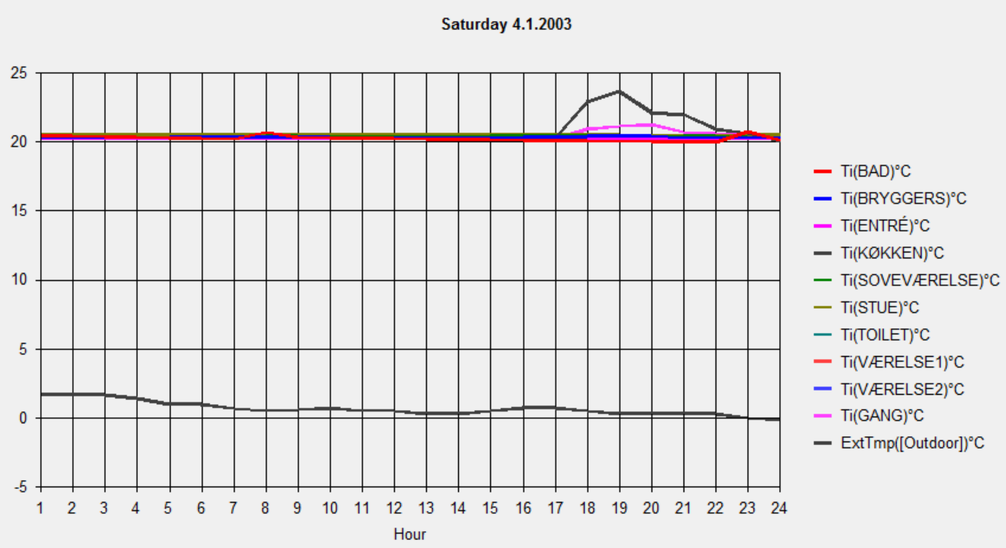
Der ses på to forskellige udskiftninger af vinduer og døre: én hvor kun glasset udskiftes, og én hvor både glasset og ramme/karm udskiftes. Først ses kun på udskiftning af glas.

Vinduerne og yderdørenes U-værdier udregnes i henhold til DS 418, og kan ses i Tabel 6.

Tabel 4 - Nye U-værdier for vinduer/døre.

Vindues-/dørtype	U-værdi $[W/m^2K]$
Vindue, køkken	1,48
Vinduer, værelser og bad	1,45
Glasparti, stue N	1,28
Glasparti, stue V (nedre del)	1,26
Glasparti, stue V (øvre del) Trekant vindue	1,42
Udvendige døre	1,52

Der simuleres for temperatursættet 52/33/20. På Figur 5 ses simulering lørdag d. 4.1.2003, hvor det ses at der er over 20 °C i alle rum i huset, når udetemperaturen er over 0 °C.



Figur 5 – Simulering for temperatursættet 52/33/20.

Når udetemperaturen er under 0 °C, er det nødvendigt at hæve fremløbstemperaturen i radiatorerne. I Tabel 5 er det undersøgt hvilke temperatursæt er nødvendigt ved forskellige udetemperaturer. Når udetemperaturen er mellem 0 °C og -5 °C er der behov for 55 °C varmt vand i fremløb til radiatorerne for at opretholde 20 °C i alle rum.

Tabel 5 - Temperaturvariation for huset med nye glas i vinduer og døre.

Temperatursæt	Udetemperatur
52/33/20	0 °C
55/33/20	-5 °C
60/33/20	-8 °C
65/33/20	-13 °C
70/33/20	-17 °C
75/33/20	-

Fra tabellen ses det, at ved at hæve fremløbstemperaturen af vandet med 23 °C til 75°C, sikres det at der ikke er under 20 °C i huset, selv når udetemperaturerne kommer helt ned på -21 °C.

Udskiftning af vinduer og døre

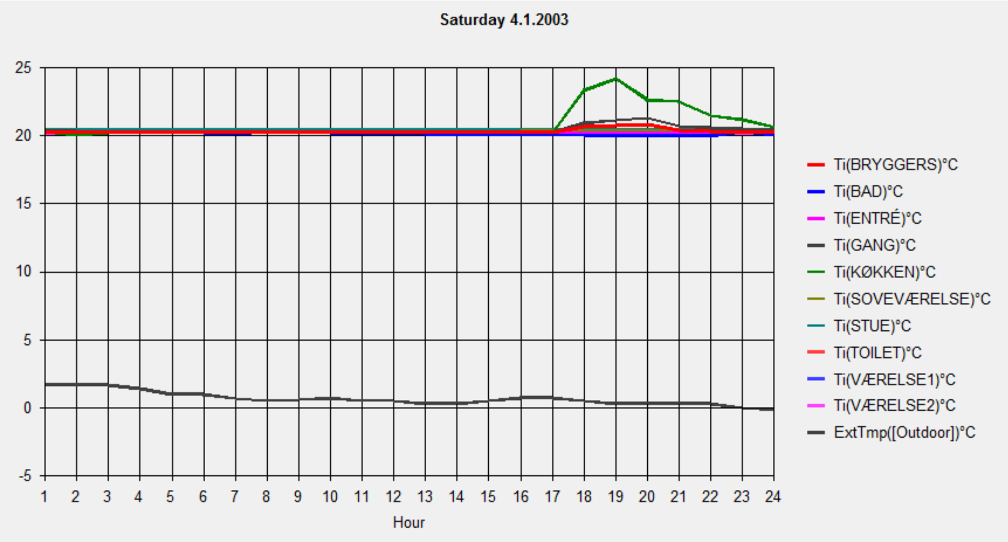
Vinduer og døre udskiftes nu med 3-lags energivinduer med argon gasfyldning. udført i træ, gummi (EPDM) og glas fiber komposit. Ruden er opbygget som 4SN-16Ar-4-16Ar-SN4, hvilket betyder, at selve glasset er 4 mm tykt og der er 16 mm argon gasfyldning mellem de 3 lag glas. SN betegner en lav emissions belægning af tinoxid, som er på overflade 2 og 5, når overfladerne af glassene nummereres fra venstre mod højre.

Vinduerne og yderdørenes U-værdier ses i Tabel 6.

Tabel 6 - Nye U-værdier for vinduer/døre.

Vindues-/dørtype	U-værdi $[W/m^2K]$
Vindue, køkken	0,84
Vinduer, værelser og bad	0,82
Glasparti, stue N	0,72
Glasparti, stue V (nedre del)	0,69
Glasparti, stue V (øvre del) Trekant vindue	0,81
Udvendige døre	0,83

Vinduerne og yderdørene indsættes i modellen og temperatursættet 49/33/20 simuleres, se Figur 6.



Figur 6 - 50/33/20 nye vinduer og døre.

Det ses, at indetemperaturene kun er tilfredsstillende når udetemperaturen ikke er minusgrader.

Igen undersøges nødvendige temperatur ved forskellige udetemperaturer, se Tabel 7.

Tabel 7 - Temperaturvariation for huset med nye vinduer og døre.

Temperatursæt	Udetemperatur
49/33/20	0 °C
50/33/20	-2 °C
55/33/20	-6 °C
60/33/20	-12 °C
65/33/20	-16 °C
70/33/20	-

Fra tabellen ses det, at ved at hæve fremløbstemperaturen af vandet fra 49 °C til 70°C, er der ikke under 20 °C i rummene, selv når udetemperaturerne kommer helt ned på -21 °C.

Slutteligt undersøges udskiftningen af radiatorerne i de mest kritiske rum.

Udskiftning af radiatorerne i de to kritiske rum

Ved at udskifte radiatorerne i badeværelset og stuen med 2PK radiatorer, behøves fremløbstemperaturen ikke hæves til 73 °C, når det minusgrader udenfor. Præcis hvor meget temperaturen behøves at hæves undersøges i det følgende.

Ved at udskifte radiatorerne i stuen og badet, er der først behov for at hæve fremløbstemperaturen når udetemperaturen kommer under -7 °C. Ligesom tidligere undersøges igen ved hvilken udetemperatur, indetemperaturerne kommer under 20 °C. I dette tilfælde er det soveværelset der har flest timer under 20 °C.

Tabel 8 - Temperaturvariation for huset med nye vinduer og døre og nye radiatorer i to rum.

Temperatursæt	Udetemperatur
45/31/20	0 °C
49/33/20	-7 °C
55/33/20	-16 °C
60/33/20	-18 °C
64/33/20	-

Af Tabel 8 ses det, at ved at udskifte radiatorerne i stuen og badeværelset behøves fremløbstemperaturen kun at hæves med 15 °C når det er -21 °C udenfor.

Energiforbrug for huset

Energiforbruget og det maksimale effektbehov kan ses i Tabel 9.

Tabel 9 – Energiforbrug og maksimalt effektbehov for de forskellige scenarier af huset.

Case	Dimensioneret varmetab (-12°C) [W]	Energi-forbrug [kWh]	Energi-forbrug pr. areal [kWh/m^2]	Maksimalt effektbehov [kW]	Nødvendig temperatur i radiatorerne ved	
					Tout=-21°C	Tout=0°C
Ingen tiltag	12 583	25 907	181	11.8	80/40/20	-
Nye glas	7 437*	19 519	136	9.7	75/33/20	52/33/20
Nye vinduer	4 108	17 178	120	8.3	70/33/20	49/33/20
Nye vinduer og radiatorer	4 108	17 178	120	8.3	64/33/20	45/31/20

For scenariet med nye vinduer gælder værdierne både for huset med de eksisterende radiatorer og når nogle af dem

Energiforbruget kan sænkes med 8 729 kWh ved at sætte nye vinduer i huset, og dertil sænkes det maksimale effektbehov med 3.5 kW.

Appendix 5

STEADY STATE HEAT LOSSES IN PRE-INSULATED PIPES FOR LOW-ENERGY DISTRICT HEATING

A. Dalla Rosa[1], *H. Li*[1], *S. Svendsen*[1]

[1] Technical University of Denmark

ABSTRACT

The synergy between highly energy efficient buildings and low-energy district heating (DH) systems is a promising concept for the optimal integration of energy saving policies and energy supply systems based on renewable energy (RE). Distribution heat losses represent a key factor in the design of low-energy DH systems. Various design concepts are considered in this paper: flexible pre-insulated twin pipes with symmetrical or asymmetrical insulation, double pipes, triple pipes. These technologies are potentially energy-efficient and cost-effective solutions for DH networks in low-heat density areas. We start with a review of theories and methods for steady-state heat loss calculation. Next, the article shows how detailed calculations with 2D-modeling of pipes can be carried out by means of computer software based on the finite element method (FEM). The model was validated by comparison with analytical results and data from the literature. We took into account the influence of the temperature-dependent conductivity coefficient of polyurethane (PUR) insulation foam, which enabled to achieve a high degree of detail. We also illustrated the influence of the soil temperature throughout the year. Finally, the article describes proposals for the optimal design of pipes for low-energy applications and presents methods for decreasing heat losses.

INTRODUCTION

The energy policy on energy conservation poses stringent requirements in the building energy sector, so that the entire DH industry must re-think the way district energy is produced and distributed to end-users [1, 2]. This is a requirement to be cost-effective in low heat density areas. Low-energy DH networks applied to low-energy buildings represent a key technology to match the benefit of an environmentally friendly energy supply sector and the advantages of energy savings policy at the end-users' side. Future buildings with a high performance envelope will lead to reduced space heating load and therefore to a lower required distribution temperature for heating. The introduction of low-energy DH networks is an appropriate and natural solution to enhance energy and exergy efficiencies.

Distribution heat losses represent a key-point for designing low-energy DH systems, due to the critical role they have in the economy of the system. The industry could meet the requirements of higher insulation series to reduce heat losses and thus saving operational costs; however, this option would increase investment and installation costs. The design principles for DH networks could instead be changed towards the use of media pipes with small nominal diameters, with a higher permissible specific pressure drop. All-year around lower supply temperature and return temperature constitute an effective option to reduce heat losses [3]. These principles have a big potential for heat supply to low-energy buildings, as explained in [4] and they are investigated in this paper.

The total length of branch pipes can be significant in proportion to the total length of the network, above all in areas with a low-energy demand density. Moreover the temperatures in the critical service lines affect the temperature level in the whole network, so that the heat losses and the temperature decay in building connection pipes are decisive for the overall performance of the system. In this paper particular focus was given to branch pipes.

State-of the art of district heating pipes

At present time DH distribution and service lines are based either on the single pipe system, where the supply/return water flows in media pipes with their own insulation, or on the twin pipe system, where both pipes are placed in the same insulated casing, or in a mixture of them. All plastic pipe systems are characterized by having the water medium pipe made of plastic (cross-linked polyethylene (PEX) or polybutylene (PB)). They are covered by insulation, usually polyurethane foam, but in some cases of PEX foam or mineral wool; the outer cover is formed by a plastic jacket. Durability of plastic pipes is not a real issue, since it has been proved that the expected life of PB pipes and PEX pipes is, respectively, more than 40 years and approx. 100 years [5]. As consequence of even lower average operational temperature, longer lifetime can be predicted according to Annex A in [6]. Studies have indicated that cross-linked polyethylene (PEX) pipes have a cost advantage over steel pipes at pipe dimensions less than DN60, due to their greater flexibility since the joints do not require welding [7]. Alternative design concepts must be considered in branch pipes from street lines to consumers' substations: a pair of single pipes, twin pipes or triple pipes. Traditionally most DH branch connections have been built with two single steel pipes: one supply pipe and one return pipe. Twin pipes can be made of steel, copper or PEX, with the supply and return pipe in the same casing. The heat losses from twin pipes are lower than from single pipes, considering same dimensions and temperatures.

Furthermore commercially available twin pipes, with dimensions up to DN200 for traditional steel media pipe or up to DN50 for PEX media-pipes are usually less expensive to install than single pipes [7]. This technology has been introduced in Nordic countries (and it is used in daily operation in many DH networks. Triple pipes might be considered in the near future, due to flexibility in the way the system can operate and lower heat losses in case of optimal configuration. The choice of house connections depends mainly on the length of the branch pipe, on supply and return temperatures, building heating load and type of substation. The latter is decisive with regard to energy performance and thermal comfort. The types of substations are typically divided into three concepts: unit with domestic hot water (DHW) storage tank, where the tank is the secondary-loop and consumer unit with DH water tank, where the tank is placed in the primary loop. In this paper branch pipe solutions are considered for the concept of a consumer unit with heat exchanger and no storage tank. Two possible configurations of user connection to the distribution line are shown in Figure 1.

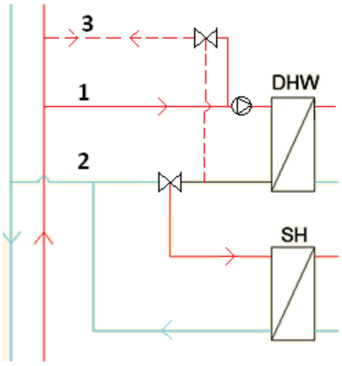


Figure 1: Sketch of a user connection with heat exchangers: twin pipe connection with/ without booster pump (1–2) and triple pipe connection (1-2-3).

1: supply

2: return

3: supply/re-circulation

A simple and cost-effective configuration is composed of the control system and two heat exchangers for, respectively, space heating (SH) and domestic hot water (DHW). The main disadvantage of such type of substation unit is that only rather short lengths of service pipes can usually be applied; otherwise it would not be possible to assure the required DHW temperature at tapping points in the required time, due to the unsatisfactory transportation time. A modified unit is therefore proposed and it is equipped with a booster pump which assures quicker response to DHW demand, although a non perfect cooling of DH water occurs when tapping of DHW starts. The concept based on twin pipes and a substation with instantaneous production of DHW in a heat exchanger is an optimal solution, if certain conditions are respected. The first requirement is that the control method gives priority to DHW preparation over space heating; the second condition is that the space heating load during summer, to keep a high level of comfort in bathrooms for example, has to guarantee a sufficient cooling of the return water. As a result media pipes with inner diameters as small as 10 mm can be applied in the primary loop and the water return temperature can be kept sufficiently low, even in summer conditions.

The triple pipe system is applicable in three different operational modes. The first one (mode I) occurs in case of DHW demand, when pipe 1 and pipe 3 both act as water supply pipes; the second operational mode (mode II) is activated when an idle water flow is supplied by pipe 1 and pipe 3 acts as re-circulation line to the supply distribution line, while the return line (pipe 2) is not active: this is often the case when there is no demand for space heating, but a small amount of water circulates in the DHW heat exchanger, keeping the loop warm to satisfy the instantaneous preparation of DHW in the required time. This system avoids an undesirable heating of the water in the return distribution line. The third operational mode (mode III) occurs during the heating season when there is only demand for space heating and no tapping of DHW: pipe 1 and pipe 2 operate as a traditional supply-return system, while there is no water flow in pipe 3. The different modes are summarized as follows:

- Operational mode I: DHW tapping, pipe 1, 2, 3 active.
- Operational mode II: supply-to-supply re-circulation, pipe 1, 3 active; pipe 2 not active.
- Operational mode III: space heating demand, pipe 1, 2 active; pipe 3 not active.

METHODS

Theory of steady state heat loss in buried pipes

In order to calculate steady-state heat losses in DH buried pipes there are analytical methods [8] and explicit solutions for the most common cases [9]. A complete review of the available literature about steady-state heat losses in district heating pipes has been carried out in [10]. Here the methods are presented with reference to the present status of the technology in the district heating sector. Furthermore key-points and critical aspects are discussed; finally, improvements in the methodology of how to calculate steady-state heat losses are proposed, with particular focus on low-temperature and medium-temperature applications. Low-temperature district heating systems are defined as networks where fluids at a temperature below 50 °C are used, while a medium-temperature district heating system is defined as using fluids at temperatures not higher than 70 °C [11, 12]. Steady-state heat losses from pre-insulated buried pipes are generally treated by use of the following equation [10], which is valid for each pipe-i:

$$q_i = \sum_{j=1}^{n} U_{ij} \cdot (T_j - T_0) \qquad (1)$$

where Uij is the heat transfer coefficient between pipe-i and pipe-j, Tj is the temperature of the water in pipe-j and T0 is the temperature of the ground. In case of two buried pipes, which is the most common application in the DH sector, the heat losses can be calculated as follows, respectively for the supply pipe and the return pipe, where T1 is the supply temperature and T2 is the return temperature.

$$q_1 = U_{11} \cdot (T_1 - T_0) + U_{12} \cdot (T_2 - T_0) =$$
$$(U_{11} + U_{12}) \cdot (T_1 - T_g) + U_{12} \cdot (T_2 - T_1)$$

Supply pipe: (2)

$$q_1 = U_{11} \cdot (T_1 - T_0) + U_{12} \cdot (T_2 - T_0) =$$
$$(U_{11} + U_{12}) \cdot (T_1 - T_g) + U_{12} \cdot (T_2 - T_1)$$

Return pipe: (3)

$$q_1 = U_{22} \cdot (T_2 - T_0) + U_{21} \cdot (T_1 - T_0) =$$
$$q_1 = U_{22} \cdot (T_2 - T_0) + U_{21} \cdot (T_1 - T_0) = (U_{22} + U_{21}) \cdot$$
$$(T_2 - T_g) + U_{21} \cdot (T_1 - T_2)$$
$$(U_{22} + U_{21}) \cdot (T_2 - T_g) + U_{21} \cdot (T_1 - T_2)$$

Equations (2) and (3) show how the heat transfer from each pipe can be seen as linear superimposition of two heat fluxes, the first one describing the heat transfer between the pipe and the ground, the second one representing the heat transfer between the supply pipe and the return pipe. The equations can also be re-arranged in the following way:

Supply pipe: (4)

$$q_1 = \left[U_{11} + U_{12} \cdot \frac{(T_2 - T_0)}{(T_1 - T_0)}\right] \cdot (T_1 - T_0) = U_1 \cdot (T_1 - T_0)$$

Return pipe: (5)

$$q_2 = \left[U_{22} + U_{21} \cdot \frac{(T_1 - T_0)}{(T_2 - T_0)}\right] \cdot (T_2 - T_0) = U_2 \cdot (T_2 - T_0)$$

Equations (4) and (5) show how the heat transfer from each pipe can be calculated by use of only one linear thermal coefficient, which is function of the temperature in this case. U-values are dependent both on temperature and time. If the time-dependency due to the ageing of the foam can be restrained by introducing effective diffusion barriers, that is not true for the intrinsic dependency on temperature. It is practice to evaluate the steady state heat loss applying a thermal conductivity value that corresponds to a hypothesized mean temperature of the insulation. Nevertheless we need models based, for example, on the finite element method (FEM) when complex geometries or a high degree of detail are requested.

Temperature dependant thermal conductivity of PUR insulation foam

In this paragraph the authors want to explain and demonstrate the importance of taking into account the temperature-dependency of the thermal conductivity of the insulation (lambda-value). The temperature gradient in the insulation foam in the radial direction is often higher then 10 °C/cm, meaning that the thermal conductivity of the material locally varies remarkably. In the example shown Figure 2, it varies more than 10% of the prescribed mean value. This affects the magnitude of the heat transfer. Considering a life cycle assessment of a DH system, the main impact to the environment is represented by heat losses [13]. The thermal conductivity of the insulation material in pre-insulated DH pipes is usually stated at a temperature of 50 °C. The lambda-coefficients were chosen according to the available data at the end of 2009; the lambda-value at 50 °C for straight pipes, axial continuous production was set to 0.024 W/(mK) and for flexible pipes to 0.023 W/(mK). Since April 2010 new results are available [14]. It is preferable to have a model that takes into account the temperature-dependency of the thermal conductivity of the insulation foam. The calculations in this paper use the following expression, if not differently stated. It derives from experimental data [15]:

λ(T) = 0.0196734 + 8.0747308·10-5.T [W/(mK)] (1)

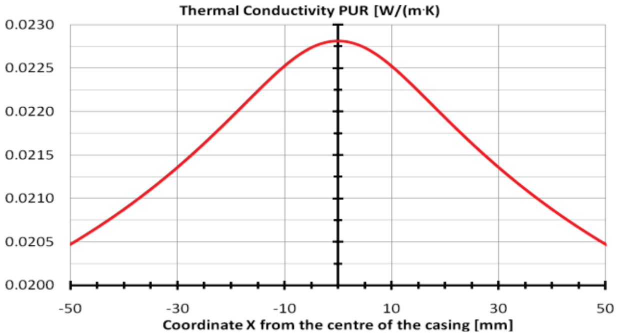


Figure 2: Thermal conductivity in the insulation, horizontal cross-section of the pipe. Pipe: Aluflex 16-16/110, temperatures supply/return/ground 55/25/8 °C.

Temperature field in the soil around the pipe

In this paper we address the question of how to create a simple yet detailed FEM model for steady state heat loss calculations. The overall heat transfer resistance between the DH water and the environment is mainly composed of the thermal resistance of the insulation and the thermal resistance of the soil; compared to these two factors, the thermal resistances of the pipe wall and the convective resistance at the surface water-pipe are in practice negligible. The insulation foam always offers the greatest share in the overall insulation effect. The contribution of the soil is smaller on small-sized pipes than on large-sized pipes. The share is smaller in Insulation Series 2 and 3 [3]. The heat conductivity coefficient of the soil is the main parameter affecting the thermal resistance of the soil itself, and its value is often unknown in practice.In the calculations we chose a value of 1.6 W/(m.K). The soil temperature influences heat losses from DH pipes. The soil layer around the heating pipes slightly warms up around the pipes. The evaluation of the temperature field in the soil is a prerequisite to create a realistic model for calculations of heat losses. Finite Element Method (FEM) simulations were carried out and temperature conditions in the soil around a typical DH service pipe, suitable for low-temperature applications were evaluated over a 10-year period.

Table 1: Thermal properties of materials.

λ	[W/(m·K)]	ρ	[kg/m³]	C_p	[J/(kg·K)]
λ_{soil}	1.6	ρ_{soil}	1600	C_{p_soil}	2000
λ_{PE}	0.43	ρ_{PE}	940	C_{p_PE}	1800
λ_{PUR}	0.023	ρ_{PUR}	60	C_{p_PUR}	1500
λ_{PEX}	0.38	ρ_{PEX}	938	C_{p_PEX}	550
λ_{Steel}	76	ρ_{Steel}	8930	C_{p_Steel}	480
λ_{Cu}	400	ρ_{Cu}	8930	C_{p_Cu}	385

The simulation calculated the soil temperature at various x-coordinates from a commercial branch pipe. The selected pipe was the Aluflex twin pipe 16-16/110. Temperatures were set at 55 °C and 25 °C, respectively for the supply pipe and the return pipe. The heat transfer coefficient at the ground surface was assumed to be 14.6 W/(m2K), including convection and radiation [16]; we set the outdoor air temperature during the year according to the harmonic function valid for the Danish climate [17]:

$$T_{air} = 8.0 + 8.5 \cdot \sin\left(2\pi \cdot \frac{M}{12}\right) \qquad (6)$$

Combined heat and moisture transfer is disregarded. The material properties are homogeneous and phase changes, i.e. freezing and thawing were not considered. Table 1 lists the material properties, used as input values also for the following models; a sketch of the slab-model, where the boundary conditions are described, can be seen in Figure 3.

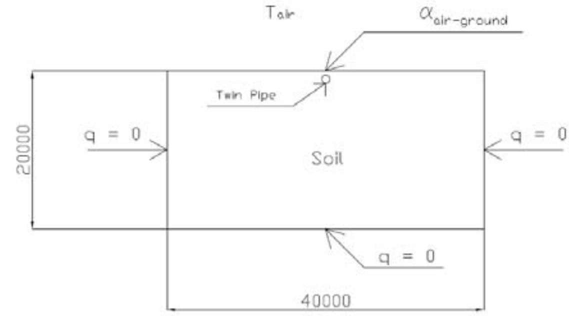


Figure 3: Sketch of the model. Dimensions are in [mm].

FEM model

A rectangle representing a semi-infinite soil domain (width: 10–20 m, height: 20–40 m) is the most used geometry to model the ground in heat loss calculations [18, 19]. In this paper a finite, circular soil domain was applied, instead. Its diameter is 0.5 m and it is equal to the distance between the surface and the centre of the casing pipe. Calculations show that the introduced simplification hardly affects the accuracy of the results. The mesh model and an example of the temperature field in a small size twin pipe are shown in Figure 4.

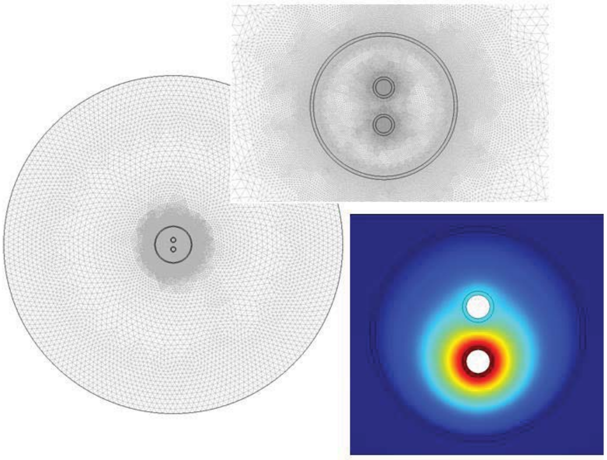


Figure 4: Mesh model of a pre-insulated twin pipe embedded in the ground (top and left). Temperature field in Aluflex twin pipe 16-16/110 (bottom-right); temperature supply/return/ground: 55/25/8 °C.

In [3], where FEM simulations were performed, it is stated that for media pipes size from DN 50 to DN 400, the deviation of the lineal thermal coefficient between the piggy-back laying (arranging the supply pipe below the return pipe) and the traditional system (horizontal laying) is less than 1%. The same conclusion can be stated for twin pipes; this is confirmed by calculations with the multipole method in [20] for two examples of twin pipe (DN 20 and DN 80) and by [10]. For twin pipes of even smaller size, such as in branch connections, the heat losses occurring in case of vertical layout are only slightly more favorable than the losses occurring on horizontally arranged pipes; this result is shown with an example in the results section.

RESULTS AND DISCUSSION

In this section we discuss the influence of the soil temperature on heat losses; next, we present the validation of the FEM models; finally we apply the method to show the potential for energy saving in the case of asymmetrical insulation of twin pipes, in the case of double pipes and triple pipes.

Temperature field in the soil

Temperature conditions in the soil around a typical twin pipe, type Aluflex 16–16/110, were evaluated over a 10-year period. Figure 5 shows the all-year temperature profiles of the outdoor air and of the ground at depth equal to 0.5 m, at three horizontal distances from the centre of the casing, during the first year of operation. No notable differences in the yearly profile were noticed in longer periods of time.

We found that in state-of-the-art well insulated twin pipes (series 2 or 3) a certain amount of soil is slightly heated up by the warm twin pipe; nevertheless the level of such heating can be neglected because its effect is not noticeable in comparison to the fact that the uncertainties about the thermal properties of the soil usually have a bigger impact. Considering yearly average temperatures, the magnitude of the soil heating is about 1 °C for distances of around 0.2-0.3 m from the centre of the casing, and less than 0.5 °C by 0.5 m. The temperature raise is considered in comparison to the undisturbed temperature of the ground at a distance of 10 m.

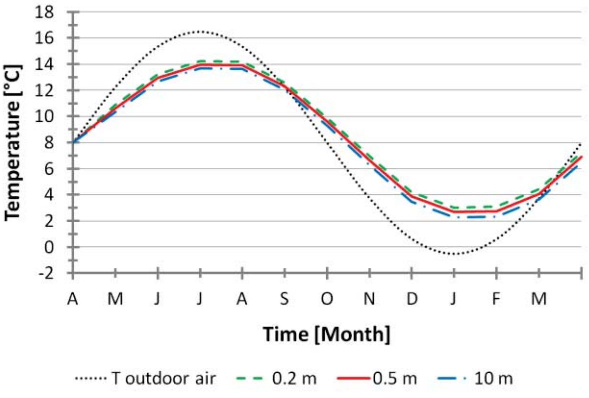


Figure 5: All-year temperature profiles of the outdoor air and of the ground at depth equal to 0.5 m and 3 horizontal distances from the centre of the casing.

FEM model: geometry of the ground and of the pipes

We considered the geometric model of the pre-insulated Aluflex twin pipe type 16-16/110; the temperatures of supply/return/ground are 55/25/8 °C. We calculated the heat losses for vertical or horizontal placement of the media pipes inside the casing, which was embedded in a rectangular or a circular model of the ground. The same calculations were repeated for other twin pipe size, up to DN 32 and other medium pipe materials, i.e. steel and copper. The results confirm that the vertical placement of the media pipes inside the insulation barely affect the heat transfer, being the difference between the two configuration less than 2% for the considered cases.

Table 2: Heat loss for various placements of the media pipes and various model of the ground.

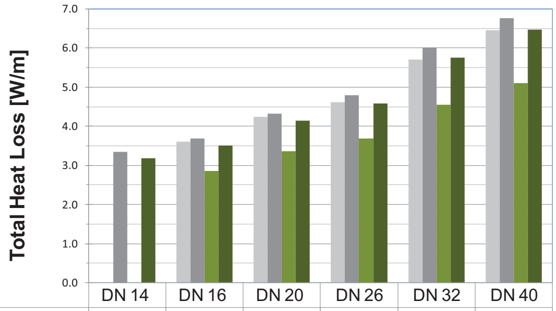
Ground model	**Media pipes layout**	**Heat loss supply [W/m]**	**Heat loss return [W/m]**	**Heat loss total [W/m]**
A	Vert.	3.79	-0.17	3.62
A	Horiz.	3.80	-0.18	3.62
B	Vert.	3.84	-0.18	3.66

A: Semi-infinite, rectangular (width x depth: 40 m x 20 m)

B: Finite, circular (diameter: 0.5 m)

Steady-state heat loss in commercial pipes

The model was validated by comparing the results from FEM simulation to the analytical calculation for pre-insulated pipes embedded in the ground [14]. Calculations were carried out for four different sizes of Aluflex twin pipes (size 14–14, 16–16, 20–20, 26–26) and for chosen sets of supply (50, 55, 60 °C), return (20, 25, 30 °C) and ground (8 °C) temperatures. The selected pipes are suitable to be used as branch pipes in low-energy demand areas. There is a good accordance between the two methods, the deviation being lower than 1%. Figure 6 gathers the values of total heat loss for the Aluflex twin pipe category; four different approaches are reported. The term "standard" is used when the effect of the temperature on the thermal properties of the insulation is neglected and the thermal conductivity of the PUR foam is thus constant. This is in accordance with [21]. The term "advanced" is used when the calculation method takes into account that the thermal conductivity of the insulation depends on the temperature. Based on the temperatures calculated for a number of points in the insulation the program calculates an average temperature for the material; the lambda-value of the insulation is then calculated as a function of such temperature. An average temperature of the ground is similarly calculated. The calculation is repeated until the mean temperature difference for the insulation material, pipe shell and surrounding soil is less than 0.005 °C for two consecutive calculations. The”standard” and “advanced” model are available online [14]. In the “FEM advanced” model we directly implemented equation (1) in the insulation domain, instead. The results indicate that in case of low-temperature operation, lower total heat losses are calculated if the temperature-dependency of the insulation lambda-value is taken into account. Moreover the heat transfer between the pipes in twin or triple pipes can be properly evaluated.



	DN 14	DN 16	DN 20	DN 26	DN 32	DN 40
■ Standard		3.61	4.24	4.62	5.71	6.45
■ FEM Standard	3.34	3.68	4.33	4.80	6.02	6.76
■ Advanced		2.86	3.36	3.69	4.55	5.10
■ FEM Advanced	3.19	3.51	4.14	4.59	5.75	6.47

Figure 6: Comparison of 4 different approaches for steady-state heat loss calculation. Aluflex twin pipe series, supply/return/ ground temperatures: 55/25/8 °C.

Asymmetrical insulation in twin pipes

The results show that improvements are possible, thanks to asymmetrical insulation (see Table 3). We proved that a better design leads to lower heat losses from the supply pipe (leading to a lower temperature drop); next, the heat loss from the return pipe can be close to zero, maintaining isothermal conditions in the return line. If commercial available casing sizes are kept, we suggest two design strategies, depending on the size of the pipes. For small pipe sizes (Aluflex: ≤ DN 26, steel: ≤ DN 50) the best design is to put the supply pipe in the centre of the casing, assuring the best possible insulation for the supply pipe. This strategy guarantees also the lowest temperature drop in the supply side, which is a critical figure in low-temperature applications.

For bigger sizes (Aluflex: ≥ DN 26, steel: ≥ DN 50) the best design is achieved by “moving up” the media pipe layout and at the same time by keeping the same distance between the media pipes as in the symmetrical case.

Double pipes

A double pipe consists of a pair of media pipes of dissimilar size, co-insulated in the same casing. It is a further development of the twin pipe concept. A sketch of a possible application of the double pipe concept is shown in Figure 7. Though these measures, network heat loss reduction is possible, in case of operation during low heating load periods.

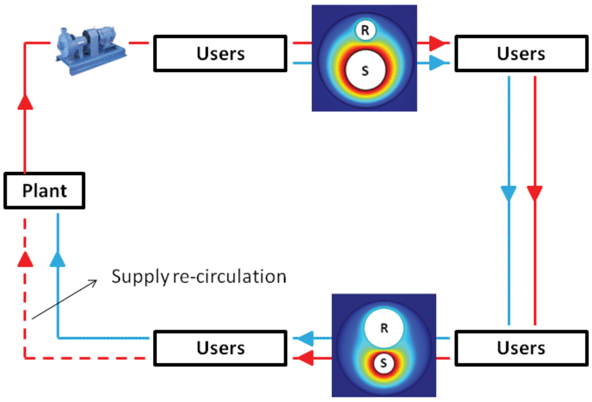


Figure 7: Sketch of the possible application of the double pipe concept in a simple district heating network.

Table 3: Comparison between asymmetrical and symmetrical insulation in twin pipes. The centre of the casing is the origin of the Cartesian system.

		Coordinates (x; y) [mm]		Heat loss [W/m]			asymm.-symm. [%]	
Size (DN)	Mat.	Sup.	Ret.	Sup.	Ret.	Tot.	Sup.	Tot.
14	Alx.	(0; 0)	(0; 27)	3.24	0.01	3.25	-7.6	2.0
16		(0; 0)	(0; 28)	3.56	-0.01	3.55	-5.1	1.1
20		(0; 0)	(0; 30)	4.16	-0.04	4.12	-4.2	-0.3
26		(0; 0)	(0; 36)	4.67	0.00	4.67	-5.1	1.9
32		(0; -16)	(0; 28)	5.54	0.00	5.54	-5.8	-2.5
50	Steel	(0; -25)	(0; 55)	5.69	-0.03	5.66	-7.7	-2.4
65		(0; -36)	(0; 60)	6.70	-0.02	6.68	-7.8	-3.2

The space heating demand in summer is diminished, except for the energy requirement in bath room heating. According to the energy balance, the reduced heating load requires less network flow rate as far as the designed building temperature drop is sustained. However, the reduction of network flow rate will increase the supply water temperature drop along the pipeline due to heat loss. As a consequence, the supply temperature at the end user may lower down below the minimum requirement. This problem is relevant to tow-energy DH systems with an already low supply temperature. This design is based on the fact that the supply line acts also as re-circulation line during low heating load periods; hence by-pass at the critical consumers are not necessary and the exergy loss due to the mixing of warm water into the return line is avoided. Furthermore the water flow in the return line has the same direction as in the supply line (clockwise in the example), so that the smallest size for the return pipes are expected in correspondence to the biggest size for the supply size, and vice versa. This results in lower local pressure differences between supply and return lines and savings in operational costs, thanks to lower heat losses. This is shown in Table 4 and Table 5, by means of two examples: the first one refers to a small to medium-size distribution network, the second one to a bigger one, being capable to supply four times more energy than the previous one.

Table 4: Comparison between a distribution network based on twin pipe (DN40-40 and DN80-80) with a distribution network based on double pipe (DN40-80 and DN80-40). Supply/return/ground temperature: 55/25/8 °C.

	Heat loss [W/m]				
Size (DN)	**Sup.**	**Ret.**	**Tot.**	**Total (system)**	**[%]**
40-40	-6.24	0.04	-6.20	Twin: -13.79	6.1
80-80	-7.66	0.07	-7.59		
40-80	-5.55	0.05	-5.58	Double: -12.94	
80-40	-7.41	0.05	-7.36		

Table 5: Comparison between a distribution network based on twin pipe (DN100-100 and DN200-200) with a distribution network based on double pipe (DN100-200 and DN200-100). Supply/return/ground: 55/25/8 °C.

	Heat loss [W/m]				
Size (DN)	**Sup.**	**Ret.**	**Tot.**	**Total (system)**	**[%]**
100-100	-7.83	-0.55	-8.39	Twin: -17.06	11.8
200-200	-8.92	0.24	-8.68		
100-200	-6.4	0.08	-6.36	Double: -15.05	
200-100	-8.07	-0.03	-8.69		

We considered an optimal placement of the media pipes in case of double pipes, thus asymmetrical insulation is applied. The total amount of insulation is used both in the twin pipe-based distribution network and in the double pipe-based one, so that the investment costs are equal in both cases. Results show that the heat loss can be reduced by 6% by means of double pipes instead of twin pipes for the low to medium-size distribution network. Even higher energy savings (around 12%) are possible in the case of the large-size distribution network.

Triple branch pipes

The development of an optimized triple pipe solution for low-energy applications is reported to show the potentiality of utilizing detailed models for steady-state heat loss calculation. In this survey focus was given on the choice of media pipes diameters as small as possible. The triple pipe geometry is based on modifications of the 14-14/110 (outer diameters in [mm] of respectively supply pipe, return pipe, casing) twin pipe design which has been reported in [18]. Four geometrical variations have been considered (see Figure 8) and the Cartesian coordinates describing the placement of media pipes inside the casing are listed in Table 6.

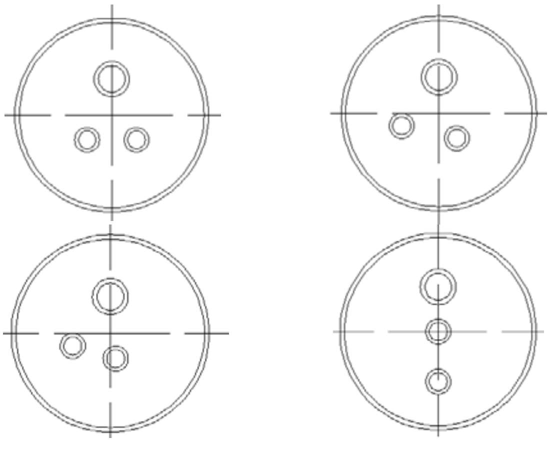


Figure 8: four different geometries for a triple service pipe type Aluflex 14-14/110.

Table 6: placement of media pipes inside the casing for four triple pipe geometries, type Aluflex 14-14-20/110.

Variation	**Coordinates (x, y) [mm]**		
	Pipe 1 (Sup.)	**Pipe 2 (Ret.)**	**Pipe 3 (Sup. or re-circ.)**
A	(14;-14)	(0;20.5)	(-14;-14)
B	(10;-14)	(0;20.5)	(-21;-7)
C	(3;-14)	(0;20.5)	(-21;-7)
D	(0; 0)	(0;25)	(0;-28)

The results of FEM simulations are listed in Table 7 for the four geometries (A, B, C, D) and the three operational modes (I, II, II), previously described. Since mode II occurs in case of no demand of space heating and then outside of the heating season, simulations were additionally performed with a more realistic temperature of the ground during that period (14 °C),considering Danish weather. This gives also an insight in the effect of ground temperature throughout the year.

Table 7: Steady state heat losses of triple pipes type Aluflex 14/14/110 for 4 geometries and 3 operational modes. Temperature supply/recirculation/return/ground: 55/55/25/8 °C.

Mode	**Geom.**	**Heat loss [W/m]**			
		Pipe 1	**Pipe 2**	**Pipe 3**	**Tot.**
I (DHW tapping)	A	2.67	-0.08	2.67	5.30
	B	2.91	-0.29	2.75	5.38
	C	2.52	-0.22	2.74	5.06
	D	2.46	0.05	2.74	5.24
II (supply-to-supply re-circulation)	A	2.67	/	2.67	5.34
	B	2.69	/	2.85	5.55
	C	2.48	/	2.70	5.18
	D	2.49	/	2.75	5.25
III (space heating)	A	3.46	0.48	/	3.95
	B	3.39	0.43	/	3.83
	C	3.41	0.35	/	3.76
	D	3.53	-0.01	/	3.53

Table 8: Steady state heat losses of triple pipes type Aluflex 14/14/110 for 4 geometries and operational mode II. Temperature supply/recirculation/ return/ ground: 55/55/25/14 °C.

	Geom.	**Heat loss [W/m]**			
		Pipe 1	**Pipe 2**	**Pipe 3**	**Tot.**
II (supply-to-supply re-circulation)	A	2.35	/	2.35	4.70
	B	2.37	/	2.51	4.88
	C	2.39	/	2.63	5.02
	D	2.20	/	2.42	4.62

We conclude that an absolute best design for the service triple pipe does not exist, but it depends on the operational mode that is chosen as critical. In fact the results reported in Table 7 and Table 8 show that geometry C gives the lowest total heat loss for operational modes I and II, while geometry D has the best thermal performance for operational mode III and for operational mode II, if a temperature of the soil of 14 °C is considered. It has to be underlined that, considering the operational mode III, geometry D shows no heating of return water; this is a situation always desirable, although it has a slightly higher heat loss from the supply pipe than the other geometries. It is proved that usually operational mode I occurs for less than 1 h/day [20]. Moreover the temperature drop in the supply pipe to the DHW heat exchanger is critical in low-temperature applications, so that it is strongly recommended to minimize the heat loss from this media pipe. Considering all this and the fact that mode III is the most likely during the heating season and mode II is the most likely outside heating season, the conclusion is that geometry D is preferable.

CONCLUSIONS

The soil temperature at 0.5 m below the surface varies between 2 °C in January-February and 14 °C in July–August, for Danish conditions. This knowledge can be used to better predict the winter peak load and the temperature drop in the distribution line during summer.

The slab-model for steady state heat loss calculations can be replaced, in case of small size distribution/service pipes, by a model where the effect of the soil is represented by a circular soil layer around the district heating pipe.

The results confirm that the vertical placement of twin media pipes inside the insulation barely affects the heat transfer, in comparison to the horizontal placement; the difference between the two configurations is less than 2% for the considered cases.

We proposed a FEM model that takes into account the temperature-dependency of the thermal conductivity of the insulation foam; in this way we enhanced the accuracy of the heat transfer calculation among pipes embedded in the same insulation.

We applied the model to propose optimized design of twin pipes with asymmetrical insulation, double pipes and triple pipes. We proved that the asymmetrical insulation of twin pipes leads to lower heat loss from the supply pipe (from -4% to -8%), leading to a lower temperature drop; next the heat loss from the return pipe can be close to zero.

It is possible to cut the heat losses by 6–12% if an optimal design of double pipes is used instead of traditional twin pipes, without increasing the investment costs.

The development of an optimized triple pipe solution was also reported. It is suitable for low-energy applications with substations equipped with heat exchanger for instantaneous production of DHW.

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Appendix 6

The 12th International Symposium on District Heating and Cooling,
September 5th to September 7th, 2010, Tallinn, Estonia

DESIGN OF LOW TEMPERATURE DISTRICT HEATING NETWORK WITH SUPPLY WATER RECIRCULATION

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ABSTRACT

The focus on continuing improving building energy efficiency and reducing building energy consumption brings the key impetus for the development of the new generation district heating (DH) system. In the new generation DH network, the supply and return temperature are designed low in order to significantly reduce the network heat loss. Meanwhile, the low network operational temperature can make a better utilization of renewable energy and further improve the CHP plant efficiency.

Though the designed return temperature is low, it may increase considerably when the heating load becomes low and the by-pass system starts to function. The aim of this paper is to investigate the influence of by-pass water on the network return temperature and introduce the concept of supply water recirculation into the network design so that the traditional by-pass system can be avoided. Instead of mixing the by-pass water with return water, the by-pass water is directed to a separated circulation line and returns back to the plant directly. Different pipe design concepts were tested and the annual thermal performances for a selected residential area were evaluated with the commercial program TERMIS. The simulation program calculates the heat loss in the twin pipe as that in the single pipe. The influence of this simplification on the supply/return water temperature prediction was analyzed by solving the coupled differential energy equations.

INTRODUCTION

In European Union, one of the major energy development targets is to reduce the building energy consumption and increase the supply of renewable energy. The introduction of European Energy Performance of Building Directive (EPBD) poses stringent requirement for the member countries to effectively reduce their building energy consumption. According to the national energy policy, the building energy consumption in Denmark will drop to 25% of current level by the year 2060, while the renewable energy share will increase from 20% to 100% at the meantime [1].

District heating (DH) benefits from economic of scale with mass production of heat from central heating plants. The significant reduction of building energy consumption and wide exploitation of waste heat and renewable energy, however, makes the current DH technologies become barriers to further increase the market share [2]. In order to sustain the economic competiveness and realize the long term sustainable development, the concept of design and operation of DH system needs to be re-examined under the new energy regulation and development trends. This is the main impetus for the development of the new generation DH system. Based on previous studies, in a properly designed in-house substation system, the network supply temperature at 55oC and return temperature at 20oC can meet the consumer space heating and domestic hot water demand [3].

The low return temperature has the advantages to reduce the network heat loss, increase CHP plant power generation capability, and utilize direct flue gas condensation for waste heat recovery. However, the return temperature can become much higher than the designed value when the heating load becomes low and the by-pass system at the critical user starts to function. In this paper, the influence of by-pass water on network return temperature was examined for a reference residential area. The concept of supply water recirculation was introduced to avoid the mixing of by-pass water and the return water. Three network design methods were tested. The annual thermal performance was evaluated with the commercial district heating network hydraulic and thermal simulation software TERMIS [4]. The simulation program calculates the heat loss in the twin pipe as that in the single pipe. The influence of this simplification on the supply/return water temperature prediction was analyzed by solving the coupled differential energy equations.

SUPPLY WATER RECIRCILUATION

The solution to overcome the excessive temperature drop along the supply pipe due to reduced flow rate is to install by-pass system at the critical user in the network. Figure 1 shows the principle of supply water by-pass. Extra flow is called based on the temperature measurement at the critical user until the minimum supply temperature requirement is met. This extra flow is then "by-passed" and sends back to the return pipe. As the by-pass flow rate may be considerable and its temperature is high, the mixing with return water will significantly increase the return water temperature which causes both increased heat loss in the return pipeline and decreased power generation capability in the CHP plant.

A desirable design approach is to maintain the by-pass system as the flow rate adjuster, while avoids the mixing of the by-pass water and the return water. This design concept is schematically shown in Fig. 2, which is realized through adding a third pipeline for supply water re-circulation. When the by-pass water is called, the circulation line will transfer the extra supply water back to the plant where it is re-heated up to the supply temperature again. On the other hand, the addition of the 3rd pipeline provides the possibility to supply water in two supply lines when the heat demand is high. The network, therefore, can be designed as two supply lines with reduced diameter together with one return line.

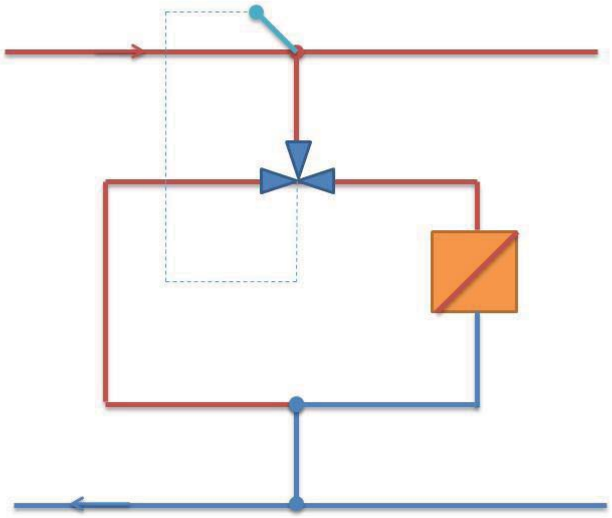


Fig. 1 Schematic for hot water by-pass system

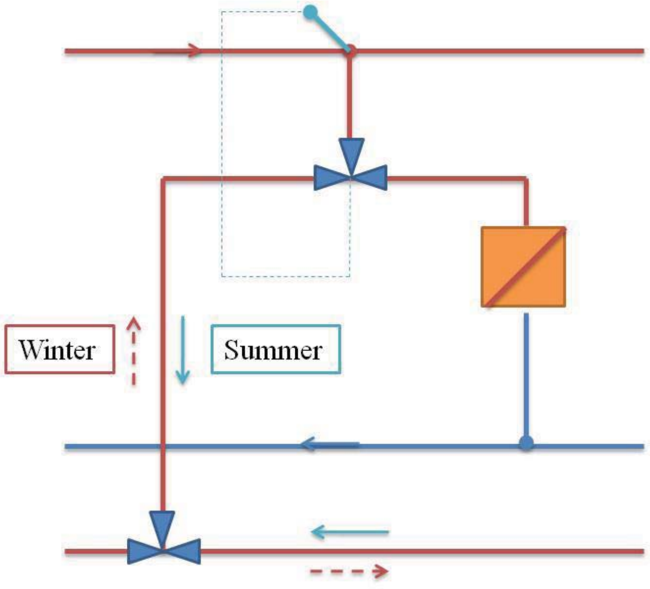


Fig. 2 Schematic for by-pass water recirculation

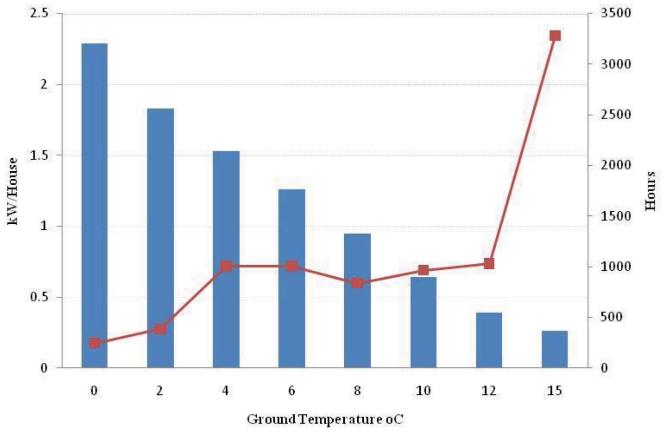


Fig. 3 Annual heating load (blue columns) and duration hours (red curve) at different ground temperature

NETWORK SIMULATION

Heating Load

The simulation was performed for a reference area with 81 low energy demand houses. The house was designed based on the building standard Class 1, following the Danish Building Regulation. The domestic hot water draw-off profile was designed similar to the Danish standard DS439 [5]. Detailed space heating and domestic hot water heating load simulation can be found from [6, 7]. Figure 4 shows the averaged heating load and the corresponding duration hours. The annual heating load is divided into 8 intervals, varying as a function of undisturbed ground temperatures which ranges from 0 to 15 ºC. The summer season lasts 3281 hours and the heating load comes only from the domestic hot water demand. The space heating is required for the rest of the year.

House Installations

Two house installations were considered in this study. Figure 4 shows the instantaneous heat exchanger (HE) in the DH system. Without a buffer tank, the branch pipe which connects directly to the HE installation must have the capability to supply the instantaneous hot water demand without causing significant pressure drop, which otherwise can be compromised by installing a booster pump. The HE design load is 32kW per houses at the network supply temperature 55oC and return temperature 22 ºC. On the other hand, simultaneous factors which are the probabilities for multiple users' concurrent use of hot water are considered for the design of street pipes and main pipes, as shown in Table 1 [3]. Fig. 5 shows the domestic hot water storage tank (DHWS) in the DH system. The DHWS design load is 8 kW per house. To avoid the legionella problem, the design temperature for DHWS is higher than HE, at 65 ºC /30 ºC for supply and return respectively.

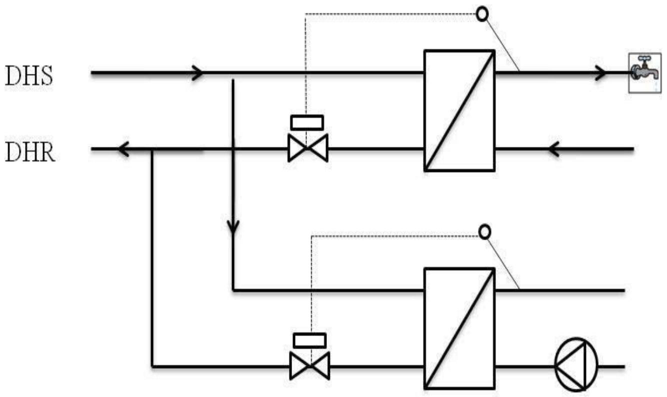
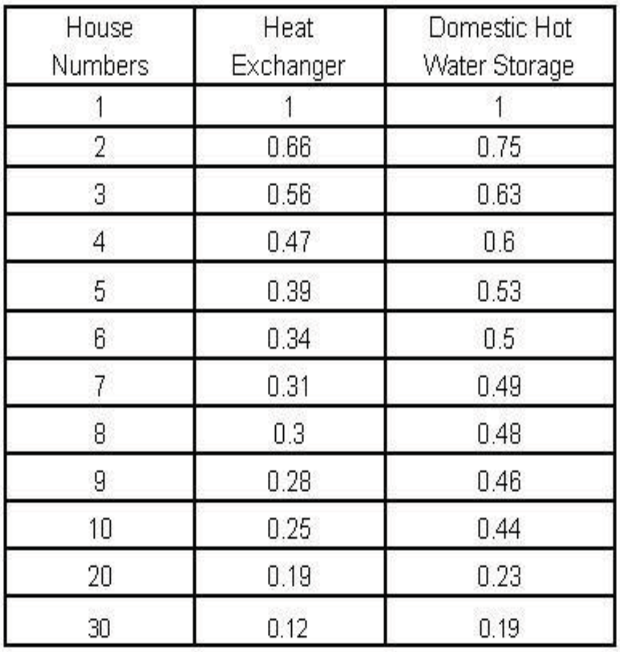


Fig. 4 In-house heat exchanger (HE) in DH system

Table 1 Simultaneous Factors



House Numbers	Heat Exchanger	Domestic Hot Water Storage
1	1	1
2	0.66	0.75
3	0.56	0.63
4	0.47	0.6
5	0.39	0.53
6	0.34	0.5
7	0.31	0.49
8	0.3	0.48
9	0.28	0.46
10	0.25	0.44
20	0.19	0.23
30	0.12	0.19

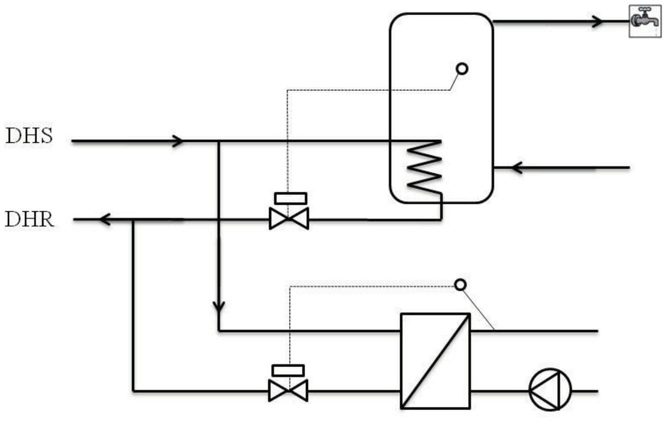


Fig. 5 Domestic hot water storage (DHWS) in DH system

District Heating Network

The DH network and the connection to the end users are shown in Fig. 6. The house is designed to connect to the plant directly through different diameter pipes which were optimized with the simulation program. The direct connection allows the primary DH network to circulate water directly into the end user installation. It is suitable for a moderate pressure level network and the differential pressure of DH network is sufficient to circulate water to the house installation. The networks and house installations are assumed to withstand maximum pressure 10 bar. The consumer differential pressure is set as 0.5 bar. It is controlled at the end user along the network critical route which is shown in green color.

Three network design scenarios were investigated for each house installation:

- Case 1: It is the reference case. The total network length is 3080 m and the network line heat density is 177 kWh/year. Network was designed in the traditional way for two pipes with one supply and one return, respectively. The differential pressure is controlled at user A. Twin pipes were selected for the DH network. They are called “reference pipe” in this paper.

- Case 2: By-pass water recirculation. A third pipeline (Fig. 6 grey color line) was introduced to separate the by-pass water with return water and re-circulate the by-pass water back to the plant. The third pipeline was sized based on the summer by-pass water flow rate. The differential pressure is controlled at point B.

- Case 3: Double pipeline supply. The main pipe (from plant to the junction point at each street) in the third pipeline which was sized in case 2 functions all year round. It acts as supply pipe during winter season and functions as supply water recirculation pipe when there has by-pass water demand. In this case, the main pipe in the reference case was resized as a portion of supply water is shared by the recirculation pipe. The connection of recirculation pipe to the reference pipe is shown with red color.

The thermal by-pass temperature was set as 50 °C for HE and 60 °C for DHWS with dead band 2 °C. The by-pass is placed on the end user at each street in case 1, while at the virtual point adjacent to the end user in case 2.

Network Heat Loss Calculation

The reference network was designed with twin pipes by placing the supply and return pipe in the same casing. Two types of twin pipes were considered in the simulation: AluFlex multilayer flexible pipe and straight steel pipe. The pipes were selected with continuous dimension ranging from Alx14 to 32 for AluFlex pipe and DN 32 to DN40 for steel pipe, based on the market available products [8]. Single AluFlex pipe is selected for the 3rd recirculation line. This 3rd pipeline can be assumed being placed in the same trench along the twin pipes. The thermal interaction between the twin and the single pipe is assumed negligible.

The heat loss in the twin pipe was calculated according to the reference [7,9]

$$q_s = U_{11}(T_s - T_g) - U_{12}(T_r - T_g) = \left[U_{11} - U_{12}\frac{T_r - T_g}{T_s - T_g}\right](T_s - T_g) = U_s(T_s - T_g) \quad [1]$$

$$q_r = U_{22}(T_r - T_g) - U_{21}(T_s - T_g) = \left[U_{11} - U_{12}\frac{T_s - T_g}{T_r - T_g}\right](T_r - T_g) = U_r(T_r - T_g) \quad [2]$$

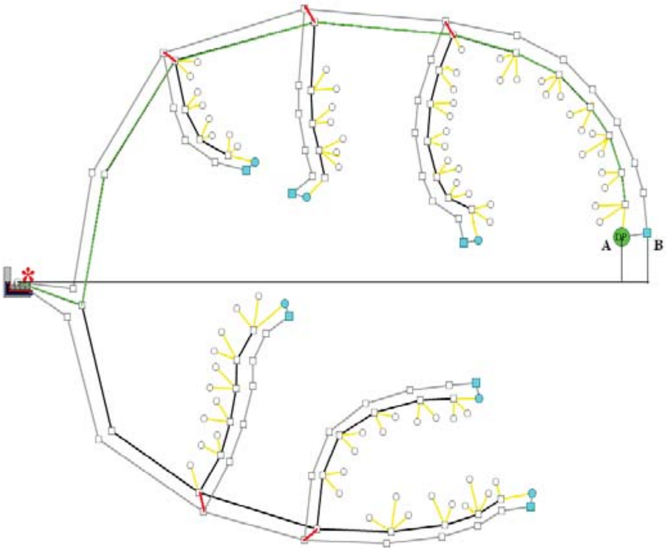


Fig. 6 District heating network

The supply and return pipe are assumed identical and placed horizontally in the same depth from the ground. The linear thermal transmittance U_{ij} reduces to $U_{11}=U_{22}=U_1$ and $U_{12}=U_{21}=U_2$. In addition, the thermal conductivity of insulation foam was assumed constant. U_1 and U_2 were then calculated with the analytical solution developed from the multi-pole method [10]. The simulation program cannot handle two heat transfer coefficients in the same pipe, U_s and U_r were derived to represent the overall heat transfer coefficients corresponding to the temperature difference between the flow and the ground.

The temperature variation along the pipeline was calculated as internal flow with isothermal boundary condition. The downstream temperature in the pipe is expressed as [4]:

$$T_d = \frac{M}{K} + \left(T_u - \frac{M}{K}\right)\exp\left(-\frac{KL}{V}\right) \quad [3]$$

T_d, T_u and T_a represent the downstream fluid temperature, upstream fluid temperature, and ambient temperature respectively. M and K are parameters include the overall heat transfer coefficient. As the overall heat transfer coefficients have to be calculated beforehand, the influence of flow temperature variation on U_s and U_r along the pipeline is neglected. It is a reasonable assumption when the thermal by-pass temperature is set close to the plant temperature, however, may cause appreciable errors if the temperature drop along the network is high.

It is worth to be noted that though the design return temperature (22 °C) is higher than ground temperature, the net heat transfer in the return pipe may absorb heat from surrounding which makes U_r negative. However, negative U_r has to be set to zero as the simulation program cannot handle negative heat transfer coefficient.

RESULTS AND DISCUSSION

Heat Exchanger

Network simulation starts from proper selection of pipe dimension, based on the design condition and the design criteria introduced in the previous section. Table 2 shows the selected pipe types and corresponding length for three different cases. Case 1 is the reference case. Flexible twin pipe Alx 20 to 32 and steel twin pipe DN32 and DN 40 were selected. The third recirculation pipe was designed in case 2 based on the summer by-pass flow rate. Pressure gradient 1500 pa/m for street pipes and 500 pa/m for main pipes were set as the dimension criteria. Though smaller pipe was suggested by the program, the Alx16 single pipe was selected as the minimum diameter pipe available on the market. It was assumed that the recirculation pipe can be used as water supply in winter in case 3. Therefore, the main pipes in the reference line were re-designed with considering that a portion of supply water goes through the recirculation line. It can be seen that the supply pipe has smaller diameter than return pipe in some sections in the twin pipe line.

Table 2 Selected pipe types and length in Case 1–3

	Pipe Types	Inner Diameter (mm)	Roughness (mm)	Length in Case 1		Length in Case 2		Length in Case 3	
				Supply (m)	Return (m)	Supply (m)	Return (m)	Supply (m)	Return (m)
Reference Network (Twin Pipe)	Alx 20/20-110	15.0	0.02	1422	1422	1422	1422	1422	1422
	Alx 26/26-125	20.0	0.02	550	550	550	550	550	550
	Alx 32/32-125	26.0	0.02	253	253	253	253	658	253
	Tws-DN32	37.2	0.1	782	782	782	782	377	782
	Tws-DN40	43.1	0.1	73	73	73	73	73	73
	Sum in twin pipes			3080	3080	3080	3080	3080	3080
Recirculation loop (Single Pipe)	Alx 16	11.6	0.02			1159	1159	1159	1159
	Alx 20	15.0	0.02			777	777	777	777
	Sum in single pipes					1936	1936	1936	1936

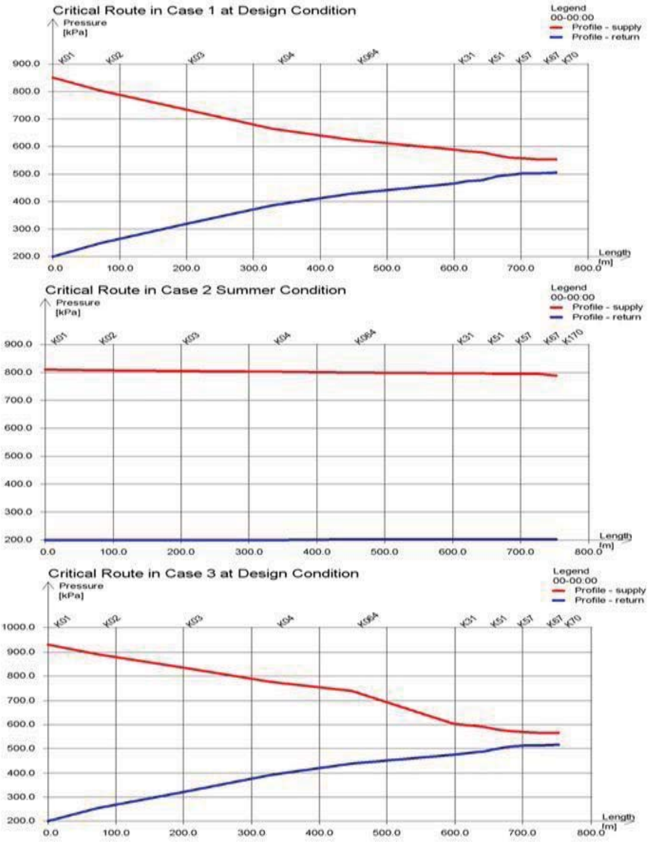
Figure 7 shows the pressure profile along the critical route. The network is designed for a 10 bar system. The minimum network static pressure is 2 bar and the minimum differential pressure at consumer is 50 kPa. The plant static supply pressure is 853 kPa in case 1 at design condition. In case 3, the designed plant supply pressure head rise to 917 kPa, which is due to the increased flow rate indicated in Table 4. The pressure drop along the reference line during summer is quite low due to the reduced flow rate. However, extra pressure head has to be applied to overcome the pressure loss along the recirculation line in Case 2. The required static supply pressure is 800 kPa during summer as a result of small dimension recirculation line.

Table 3 shows the simulation results for case 1. By-pass is required when the heating load is smaller than 1.53 kW. The return water temperature increases along with the increase of by-pass water flow rate. In summer, the amount of by-pass water flow rate exceeds the actual flow rate passing through the consumer, and the return temperature at the plant increases up to 35.5 ºC. The heat loss in the return pipe is accounted when the plant return temperature is raised to higher than 30 ºC.

Simulation results for case 2 and case 3 are shown in Table 4. They were put in the same table as case 2 operates when there has by-pass requirement, while case 3 operates in the rest seasons. Italic is used for case 3 to distinguish the two cases. Thanks to the recirculation line, the return temperature at the plant in the reference line remains low at 22 ºC, while the return temperature in the recirculation line can reach 44 ºC in the summer, after deducting the single pipe heat loss. The low plant return temperature can help extract more power in the CHP plant or be used in other circumstance like direct flue gas condensation. On the other hand, high temperature return water in the recirculation pipe can be re-heated by an additional heat exchanger or boiler with minimum energy input.

Case 2 has higher return pipe heat loss comparing with case 1 due to the introduction of recirculation line. At constant supply temperature 55 ºC, the heat transfer coefficient Us decreases with increase the return water temperature. As shown in Table 3, the return water temperature in case 2 (at 22 º C) is lower than that of in case 1. This leads to a higher heat loss in the supply pipe in case 2. As a consequence, more by-pass flow is required to compensate the extra supply pipe heat loss, therefore, the by-pass flow rate in case 2 is higher than in case 1 in the summer season.

Supply water in the recirculation pipeline in winter increases the supply pipe heat loss in case 3. The concept of double pipe supply may not economical feasible, according to the simulation results. However, it may be used as an alternative solution to supply water in the 3rd pipeline under extreme whether condition, which otherwise has to raise the plant supply temperature to meet the increased heating demand. Furthermore, results in table 4 were limited to fixed recirculation pipe diameters. The double pipe supply concept may be economical feasible by free selection both reference pipe and recirculation pipe diameter with the objective to minimize the annual network operational cost or exergy consumption. This study is out of the scope of current paper due to the limitation of the simulation program.


Critical Route in Case 1 at Design Condition

Critical Route in Case 2 Summer Condition

Critical Route in Case 3 at Design Condition

Fig. 7 Pressure profile on the critical route in Case 1–3

Table 3 Simulation results in Case 1

Power per house (kW)	Duration hours (hrs)	Heat loss in supply pipe (kW)	Heat loss in return pipe (kW)	Total heat loss (kW)	Return temperature at plant (K)	Flow through consumer (kg/s)	By-pass flow rate (kg/s)	Total flow rate (kg/s)	By-pass to total flow rate %
0.26	3281	11.22	1.56	12.78	35.5	0.18	0.19	0.37	52.49
0.39	1032	12.48	1.27	13.75	32.5	0.25	0.18	0.43	41.81
0.64	966	14.45	0.00	14.45	29.1	0.39	0.15	0.54	27.61
0.95	837	15.09	0.00	15.09	24.6	0.56	0.09	0.65	13.98
1.26	1007	15.70	0.00	15.70	23.7	0.72	0.07	0.79	8.61
1.53	1007	16.23	0.00	16.23	22.8	0.87	0.00	0.87	0.00
1.83	384	16.80	0.00	16.80		1.02	0.00	1.02	0.00
2.29	246	17.25	0.00	17.25		1.25	0.00	1.25	0.00

Table 4 Simulation results in Case 2 (First 5 rows) and Case 3 (Last 3 rows with italic)

Power per house (kW)	Duration hours (hrs)	Heat loss in supply pipe (kW)	Heat loss in return pipe (kW)	Total heat loss (kW)	Return temperature at plant (K)	Flow through consumer (kg/s)	By-pass flow rate (kg/s)	Total flow rate (kg/s)	By-pass to total flow rate %
0.26	3281	12.90	5.10	18.00	44	0.18	0.24	0.42	56.63
0.39	1032	13.75	5.47	19.22	42.7	0.26	0.20	0.46	44.24
0.64	966	14.44	5.56	20.00	40	0.39	0.15	0.54	26.92
0.95	837	15.08	5.32	20.39	34	0.56	0.08	0.64	12.94
1.26	1007	15.69	4.92	20.61	27.2	0.72	0.05	0.78	6.79
1.53	*1007*	*20.32*	*0.00*	*20.32*				*0.90*	
1.83	*384*	*21.11*	*0.00*	*21.11*				*1.05*	
2.29	*246*	*22.00*	*0.00*	*22.00*				*1.28*	

Domestic Hot Water Storage Tank

Table 5 shows the pipe types and corresponding length in the DHWS installation. Alx 14 was selected as branch pipe due to the smaller design heating load. Similar to the HE, the by-pass flow rate exceed the actual flow rate through the consumer in summer season. The plant mixed return water temperature in case 1 is 46 °C. The introduction of the recirculation line can keep the plant return temperature in reference line as low as 30 °C, while increases the return temperature in the recirculation pipe to 54 °C at the plant. Extra heat loss has to be tolerated due to the recirculation pipe in both case 2 and case 3.

Table 5   Selected pipe types and length in Case 1–3

	Pipe Types	Inner Diameter (mm)	Roughness (mm)	Length in Case 1		Length in Case 2		Length in Case 3	
				Supply (m)	Return (m)	Supply (m)	Return (m)	Supply (m)	Return (m)
Reference Network (Twin Pipe)	Alx 14/14-110	10.0	0.02	1543	1543	1543	1543	1543	1543
	Alx 16/16-110	11.6	0.02						
	Alx 20/20-110	15.0	0.02	377	377	377	377	377	377
	Alx 26/26-110	20.0	0.02	179	179	179	179	179	179
	Alx 32/32-110	26.0	0.02					126	
	Tws-DN32	37.2	0.1	909	909	909	909	783	909
	Tws-DN40	43.1	0.1	73	73	73	73	73	73
	Sum in Twin Pipes			3080	3080	3080	3080	3080	3080
Recirculation Loop (Single Pipe)	Alx 16	11.6	0.02				1043	1043	1043
	Alx 20	15.0	0.02				893	893	893
	Sum in Single Pipes						1936	1936	1936

Table 6 Simulation results in Case 1

Power per house (kW)	Duration hours (hrs)	Heat loss in supply pipe (kW)	Heat loss in return pipe (kW)	Total heat loss (kW)	Return temperature at plant (K)	Flow through consumer (kg/s)	By-pass flow rate (kg/s)	Total flow rate (kg/s)	By-pass to total flow rate %
0.26	3281	12.05	3.30	15.35	45.6	0.1647	0.2317	0.40	58.45
0.39	1032	13.30	2.74	16.04	42.8	0.2361	0.2144	0.45	47.59
0.64	966	15.13	0.00	15.13	39.1	0.3702	0.1794	0.55	32.65
0.95	837	15.68	0.00	15.68	34.7	0.528	0.1193	0.65	18.43
1.26	1007	16.22	0.00	16.22	32.7	0.6822	0.0779	0.76	10.25
1.53	1007	16.65	0.00	16.65		0.8226	0	0.82	0.00
1.83	384	17.17	0.00	17.17		0.9652	0	0.97	0.00
2.29	246	17.69	0.00	17.69		1.182	0	1.18	0.00

Table 7 Simulation results in Case 2 (First 5 rows) and Case 3 (Last 3 rows with italic)

Power per house (kW)	Duration hours (hrs)	Heat loss in supply pipe (kW)	Heat loss in return pipe (kW)	Total heat loss (kW)	Return temperature at plant (K)	Flow through consumer (kg/s)	By-pass flow rate (kg/s)	Total flow rate (kg/s)	By-pass to total flow rate %
0.26	3281	13.83	6.84	20.67	53.5	0.17	0.28	0.45	62.43
0.39	1032	14.55	7.22	21.77	52	0.24	0.25	0.48	50.60
0.64	966	15.13	7.32	22.45	49.6	0.37	0.18	0.55	32.81
0.95	837	15.67	7.19	22.86	44.4	0.53	0.12	0.64	17.98
1.26	1007	16.12	6.77	22.89	37	0.68	0.07	0.75	9.55
1.53	*1007*	*21.59*	*0.00*	*21.59*				*0.86*	
1.83	*384*	*22.37*	*0.00*	*22.37*				*1.00*	
2.29	*246*	*23.17*	*0.00*	*23.17*				*1.22*	

Further Discussion on Heat Transfer

As shown in Eq. 1–3, the simulation program simplifies the calculation of the heat loss in the twin pipe as that in the single pipe. The influence of the adjacent pipe was accounted through converting the linear thermal transmittance U_{ij} to the overall heat transfer coefficients U_s and U_r , with pre-assumed constant network supply/return temperatures. To assess the influence of this simplification on the temperature predication, the thermal interaction between the supply and return pipes was calculated by solving the coupled pipe heat transfer differential equations. The governing equations for supply and return pipes can be expressed as:

$$\frac{dT_s}{dx} + \frac{U_1}{\dot{m}c_p}\left(T_s - T_g\right) - \frac{U_2}{\dot{m}c_p}\left(T_r - T_g\right) = 0 \qquad [4]$$

$$-\frac{dT_r}{dx} + \frac{U_1}{\dot{m}c_p}\left(T_r - T_g\right) - \frac{U_2}{\dot{m}c_p}\left(T_s - T_g\right) = 0 \qquad [5]$$

The boundary conditions can be expressed as:

$$T_s(x = 0) = T_{s0}, T_r(x = L) = T_{rL} \qquad [6]$$

The dimensionless temperature is introduced with:

$$\theta_s = T_s - T_g, \theta_r = T_r - T_g \qquad [7]$$

The governing equations then change to:

$$\frac{d}{dx}\begin{bmatrix}\theta_s\\ \theta_r\end{bmatrix}=\begin{bmatrix}-\alpha_1 & \alpha_2\\ -\alpha_2 & \alpha_1\end{bmatrix}\begin{bmatrix}\theta_s\\ \theta_r\end{bmatrix} \quad [8]$$

Where $\alpha=\frac{U}{\dot{m}c_p}$

The boundary conditions change to :

$$\theta_{s0}=T_{s0}-T_g, \theta_{rL}=T_{rL}-T_g \quad [9]$$

The system linear ordinary differential equations can be solved with Eigen value method or with *Laplace* transformation. The *Laplace* transformation was applied in this study. Eq. 8 is transformed to:

$$\begin{bmatrix}s+\alpha_1 & -\alpha_2\\ \alpha_2 & s-\alpha_1\end{bmatrix}\begin{bmatrix}\bar{\theta}_s(s)\\ \bar{\theta}_r(s)\end{bmatrix}=\begin{bmatrix}\theta_{s0}\\ \theta_{r0}\end{bmatrix} \quad [10]$$

The final solutions are given as:

$$\theta_s(x)=Aexp\left(-x\sqrt{\alpha_1^2-\alpha_2^2}\right)+Bexp\left(x\sqrt{\alpha_1^2-\alpha_2^2}\right) \quad [11]$$

$$\theta_r(x)=Cexp\left(-x\sqrt{\alpha_1^2-\alpha_2^2}\right)+Dexp\left(x\sqrt{\alpha_1^2-\alpha_2^2}\right) \quad [12]$$

Where :

$$A=\frac{\theta_{s0}}{2}-\frac{\theta_{r0}\alpha_2-\theta_{s0}\alpha_1}{2\sqrt{\alpha_1^2-\alpha_2^2}},\ B=\frac{\theta_{s0}}{2}+\frac{\theta_{r0}\alpha_2-\theta_{s0}\alpha_1}{2\sqrt{\alpha_1^2-\alpha_2^2}} \quad [13]$$

$$C=\frac{\theta_{r0}}{2}+\frac{\theta_{s0}\alpha_2-\theta_{r0}\alpha_1}{2\sqrt{\alpha_1^2-\alpha_2^2}}, D=\frac{\theta_{r0}}{2}-\frac{\theta_{s0}\alpha_2-\theta_{r0}\alpha_1}{2\sqrt{\alpha_1^2-\alpha_2^2}} \quad [14]$$

Tws- DN32, which is the longest main pipe in HE of case 1, is selected for the assessment with U_1=0.141 and U_2=0.0523. The pipe length is assumed 500 m. Ground temperature ranges from 0 to 15 °C. The inlet of supply and return temperatures are known as 55 °C and 22 °C respectively. The outlet temperature of supply pipe is controlled as 50 °C and 45 °C, respectively.

Table 8 shows the temperature prediction based on single pipe simplification and the coupled pipe equations. T_Difference represents the coupled solution minus the single pipe solution. When the temperature drop along the supply pipe is controlled at 5 °C, the prediction between the single pipe and the coupled pipe is very close. The prediction errors increase with increase the ground temperature. The single pipe approach predicts lower supply water temperature and higher return temperature than those of coupled pipe solutions. It was also observed that when the ground temperature is higher than 4 °C, the net heat transfer effect in the return pipe is to absorb heat to the surrounding.

Table 8 Pipe temperature predication comparison (supply outlet temperature is controlled at 50°C)

Ground Temp	Us W/m/K	Ur W/m/K	Ts_O_Double (oC)	Ts_O_Single (oC)	Ts_Difference (oC)	Tr_I_Double (oC)	Ts_O_Single (oC)	Tr_Difference (oC)	Mass flow rate (kg/s)
0	0.1201	0.0102	50.00	49.97	0.035	21.73	21.82	-0.09	0.1495
2	0.1213	0.0024	50.00	49.97	0.036	21.86	21.96	-0.10	0.1454
4	0.1225	-0.0072	50.00	49.97	0.038	22.00	22.11	-0.11	0.141
6	0.1239	-0.0192	50.00	49.96	0.039	22.15	22.27	-0.13	0.1365
8	0.1254	-0.0346	50.00	49.97	0.040	22.30	22.44	-0.14	0.1323
10	0.1271	-0.0551	50.00	49.97	0.042	22.46	22.63	-0.17	0.128
12	0.1288	-0.0839	50.00	49.96	0.043	22.64	22.85	-0.21	0.1234
15	0.1318	-0.1579	50.00	49.96	0.045	22.93	23.22	-0.30	0.117

The by-pass water temperature in this study was set in a conservative way. In many practices, the by-pass water can be set 10 °C lower than the supply water temperature. Even lower by-pass temperature is proposed for the low temperature district heating network [3]. Table 9 shows the simulation results based on a10 °C temperature drop along the supply pipe. It shows the prediction errors increase in both supply and return pipes. The heat transfer was predicted in a reverse trend in the return pipe at 4 °C. Considerable prediction error was found in the return pipe at high ground temperature.

It is worth to be noted that the increase of supply temperature drop has more influence on the return pipe temperature prediction than that of supply pipe. The reason can be explained from the expression of U_s and U_r in Eq. 1–2. As the magnitude of T_s-T_g is higher than T_r-T_g, the same amount of return water temperature variation will have more influence on U_r than U_s, therefore causes a larger prediction error in the return pipe than in the supply pipe.

Table 9 Pipe temperature predication comparison (supply outlet temperature is controlled at 45 °C)

Ground Temperature	Us W/m/K	Ur W/m/K	Ts_O_Double (oC)	Ts_O_Single (oC)	Ts_Difference (oC)	Tr_I_Double (oC)	Ts_O_Single (oC)	Tr_Difference (oC)	Mass flow rate (kg/s)
0	0.1201	0.0102	45.00	44.87	0.137	21.27	21.62	-0.36	0.0705
2	0.1213	0.0024	45.00	44.86	0.142	21.52	21.92	-0.40	0.0682
4	0.1225	-0.0072	45.00	44.85	0.146	21.79	22.24	-0.45	0.066
6	0.1239	-0.0192	45.00	44.85	0.151	22.07	22.58	-0.51	0.0638
8	0.1254	-0.0346	45.00	44.85	0.155	22.97	22.38	-0.59	0.0616
10	0.1271	-0.0551	45.00	44.84	0.160	22.70	23.41	-0.71	0.0593
12	0.1288	-0.0839	45.00	44.84	0.164	23.05	23.92	-0.87	0.0571
15	0.1318	-0.1579	45.00	44.83	0.169	23.61	24.95	-1.33	0.0537

CONCLUSION

In this paper, a preliminary study was conducted on the influence of by-pass flow on the network return water temperature in a designed low temperature DH network. The concept of supply water recirculation was introduced to avoid the mixing of by-pass water to the return water. Double pipe water supply concept was tested to use the recirculation pipe supply water during winter season. Two different house installation modes were considered in the analysis.

The by-pass water significantly increases the return water temperature in the traditional design. The mixed return temperature can reach 35.5 °C for HE and 45.6 °C for DHWS. With applying the by-pass water recirculation, this return temperature can be maintained at 22 °C, while the re-circulated by-pass water can be kept as high as 44 °C and 53.5 °C for HE and DHWS at the plant, respectively. It was found that the double pipe supply leads to the highest network heat loss. However, the conclusion that whether the concept of double pipe supply is inferior to other network design methods can only be drawn after further network thermal-economic optimization.

The simulation program simplifies the twin pipe heat transfer prediction as a single pipe, and neglects the return pipe heat loss when the return pipe absorbs heat from the surroundings. The temperature prediction errors due to the single pipe assumption were analyzed through solving the coupled supply/return pipe differential energy equations. The prediction errors increase with increase the allowable temperature drop in the network. Considerable error was found for the return pipe at high ground temperature.

NOMENCLATURE

c_p = specific heat capacity [J/kg.K]

q = Heat transfer rate [kW / m]

s = Laplace transform variable

T = Temperature [K]

U = Overall heat transfer coefficient [kW /m.K]

U_{ij} = Linear thermal transmittance [kW/m.K]

$\dot{m}$ = mass flow rate [kg/s]

Greek Letter

θ = Dimensionless temperature

Subscripts

g = Undistributed ground

r = Return

s = Supply

u = Upstream

d = Downstream

Abbreviation

DH = District heating

HE = Heat exchanger

DHWS = Domestic hot water storage tank

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Appendix 7

A DIRECT HEAT EXCHANGER UNIT USED FOR DOMESTIC HOT WATER SUPPLY IN A SINGLE-FAMILY HOUSE SUPPLIED BY LOW ENERGY DISTRICT HEATING

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ABSTRACT

The increasing number of new and renovated buildings with reduced heating requirements will soon make traditional District Heating (DH) systems uneconomic. To keep DH competitive in the future, the heat loss in DH networks needs to be reduced. One option is to reduce the supply temperature of DH as much as possible. This requires a review of the behaviour of the whole domestic hot water (DHW) supply system with focus on the user comfort and overall costs. This paper describes some practical approaches to the implementation of this Low Energy District Heating (LEDH) concept. It reports on the testing of the dynamic behaviour of an Instantaneous Heat Exchanger Unit (IHEU) designed for DHW heating and space heating in detached family houses supplied by LEDH ensuring an entry-to-substation temperature of 51 °C. We measured the time it takes for the IHEU to produce DHW with a temperature of 42 °C and 47 °C when the tap is opened. Measurements were made for control strategies using internal and external by-pass and no by-pass. Our results show the importance of keeping the branch pipe warm if comfort requirements are to be fulfilled, but this involves higher user costs for heating. To increase user comfort without increasing costs, we propose the whole-year operation of floor heating in bathrooms, partly supplied by by-pass flow.

INTRODUCTION

District Heating (DH) is a well known concept of providing buildings with heat for space heating (SH) and Domestic Hot Water (DHW) heating in economical and environmentally friendly way. Nowadays, building regulations have been introduced worldwide and are pushing to reduce energy consumption in buildings, because 40% of all energy consumption takes place in buildings. The energy policy of European Union is recently focused on energy savings, reducing production of CO_2 and increasing the ratio of renewable energy [1]. DH is one of the most suitable solutions to achieve these goals for building sector and it gives high priority for further development of DH. But recenlty used traditional high and medium temperature DH systems are not optimal solution for the future. Sooner or later, energy consumption of all buildings will be in accordance with low energy building regulations and it will form areas with lower heat demand than nowadays. Currently used DH networks will not be able supply these areas in economical way, because the ratio between network heat losses and heat consumption in buildings would be unacceptable and thus cost of heat for end users will increase and DH systems will loose concurrency with other solutions, e.g. heat pumps. Recently, research in DH is focused to find the way how to use DH in areas with low energy buildings and how to increase ratio of heat produced by renewable sources of energy as solar heat plants or heat pumps driven by electricity from renewable sources.

One of interesting application of renewable energy in DH is use of decentralised heat sources as e.g. solar collectors installed on roofs of individual buildings, supplying heat to DH network, but it still needs more time and work to develop new substations and new concept of DH networks to be able to handle these new features. The solution for future development of DH is to reduce heat losses of DH networks by means of pipes with better insulation properties e.g. twin pipes, use better concepts of network design (circular network configuration, possibility of using circulation line for main pipes) and to reduce the supply temperature of district heating water to lowest level as possible.

The District Heating Systems designed due to this philosophy are called Low Energy District Heating Systems (LEDH). The main focus in LEDH system is to reduce heat losses from network as much as possible, exploit more sources of renewable energy for heat supply and still maintain or improve level of comfort for users, because without high level of comfort this concept can’t be successful. LEDH concept was reported e.g. in project “Development and Demonstration of Low Energy District Heating for Low Energy Buildings [2], where theoretical case study documented, that LEDH concept is a good solution for future and even in sparse housing areas is fully competitive to heat pumps. This article is focused on application of LEDH for DHW heating. Considerations related to use of LEDH for space heating will be reported in future in another article.

LOW TEMPERATURE DISTRICT HEATING CONCEPT

Reduced risk of Legionella by use of system with minimal volume of DHW

Since LEDH is mainly developed for low energy buildings already designed with low temperature space heating, the lowest acceptable forward temperature of LEDH system is defined by requirement for DHW supply temperature. The hygienic requirement for heating of DHW is due to recent standards 50 °C for single-family houses and 55 °C for multi-storey buildings [3] where DHW circulation is used. In case of using circulation, temperature of recirculated water should never fall below 50 °C. These requirements are based on need to avoid Legionella growth in DHW pipes and storage tanks. It is widely believed, that Legionella grow in temperature range between 46 °C – 20 °C, in systems with high volume of water. Mentioned temperature levels are made in order to assure comfort and hygienic requirements in furthest tap away from a heat source. It is important to say, that there is high level of discrepancy among different results and national standards focused on Legionella.

Due to German Standard W551 [4], temperature of DHW can be below 50 °C and not cause Legionella promotion, if total volume of DHW system connected to one heat source is lower than 3 L. From literature studied, it can be concluded that requirements to produce DHW with temperature higher than 50 °C are defined for an old fashion DHW building installations, which can be characterized as systems with vertical riser, branched pipes with bigger diameter (increasing water volume of the system), using DHW circulation. For new and renovated buildings, DHW installations are designed in much better manner, with individual connection of DHW pipes between each tap and source of DHW and with maximally reduced pipe diameter, defined by requirements for noise propagation and pressure drop.

Due literature, danger of Legionella growth in DHW system is influenced by temperature of DHW, nutrients in DHW, laminar or turbulent flow in the DHW pipes and water stagnation [5]. Several on site measurements were performed in buildings using DH for DHW heating. From results of Martinelli [6] and Mathys [7] can be concluded, that Instantaneous Heat Exchanger Unit (IHEU) tend to have much less problems with Legionella than traditional units with DHW storage tank. Both studies concluded, that these findings are caused by the fact that in IHEU, DHW is produced with temperature 60 °C, while in case of storage units only with temperature 50 °C. But is necessary to mention, that in case of traditional DHW storage tanks, overall volume of DHW in a system is much higher than in case of IHEU system. Due to our knowledge, there is not reported investigation of Legionella in DHW system using IHEU, producing DHW with temperature below 50 °C and reduced volume of the system below 3L.

For single family houses with appropriate close location of tapping points, volume of DHW in IHEU and pipes will be lower than 3 L and thus temperature of 50 °C on primary side will not cause Legionella problems. For multi-storey buildings, district heating substations for each flat is a state of the art solution [8]. In this case, each flat has own completely separated DHW system (with volume of water below 3 L) and thus has increased users comfort and no huge DHW systems with circulation, where Legionella is forming and spreading [9]. The other advantage of using flat station in multi-storey buildings is individual metering of each flat and complete control over space heating and DHW preparation, which is positively affecting energy savings. With properly designed DHW building installations, supply temperature of LEDH will be defined by requirements for users comfort. These requirements are discussed in following text.

Users comfort in DHW supplied by LEDH

Another important question, when concerning DHW systems is level of user comfort. From comfort point of view, requirements for temperature and waiting time for DHW can be specified. Due to Danish Standard DS439 “Code of Practice for domestic water supply installations”, [10] temperature of DHW should be 45 °C in kitchen and 40 °C in other taps, provided with nominal flowrate and desired temperature reached within “reasonable” long time, without significant temperature fluctuations. It is a question, if requirement of 45 °C degrees for kitchen tap is not too high, but argument of problems with fat dissolving from dishes can be objected and should be investigated. Based on mentioned standard, desired temperature of DHW flowing from fixture is 45 °C. But in order to define desired forward temperature of LEDH system, we should be aware of temperature drop in DH network, in user’s substation and in DHW installations in building. The temperature drop in DH network is not in focus of this paper, so our goal is to find needed temperature level at the entrance of substation to produce 45 °C from tap in building. Desired temperature will be found by experimental measurement of LEDH substation later in article.

Beside temperature requirements, users comfort is influenced by time needed for DHW to reach a fixture after tapping was started. This waiting time is in following text called “tap delay”. Due to DS439, suggested value for tap delay is 10 sec and it is defined in order to avoid wasting of water and to protect users against too long waiting times for DHW. In large multi-storey buildings with centralised preparation of DHW, short tap delay and measures avoiding Legionella growth are assured by circulation line of DHW, but not properly designed or maintained DHW circulation is quite often responsible for increased risk of Legionella [11]. Another disadvantage of DHW circulation is big heat losses, sometimes even bigger than net energy needed for DHW heating [8]. The 10 sec waiting time is not rule and for some people it is a long time, for some people short, but this value is used to evaluate tested concepts if they are fulfilling requirements for high level of users comfort or not. An overall tap delay can be studied from different angles. From dynamic point of view, tap delay consists of transportation time needed for "new volume" of water travel to tap and dynamic thermal behaviour of passed components, i.e. pipes and substation. From point of view related to location, it consists of three parts, tap delay in branch pipe (pipe from DH pipe in street to users substation), in DH substation and in DHW system in building. A tap delay in branch pipe and substation are related to DH network and substation's control system strategy, while tap delay in DHW pipes in buildings without DHW circulation are defined only by thermal capacity of pipes, volume of water in individual pipes, nominal flow and to some extend also by their insulation.

Tap delay in DHW system in building

For DHW systems with individual feeding pipes and overall volume of pipes lower than 3 L, DHW circulation is not needed, because waiting time for DHW with desired temperature is not critical. In Table 1, transport delays for individual fixtures in typical house built in pilot LEDH project in Larch Garden - Lystrup, Denmark [11] are presented. It should be mentioned, that data are only transport delay, without dynamic behaviour of cooled pipe. From Table 1 can be seen, that reasonably designed close locations of fixtures, not so far away from substation, lead to maximal transport delay around 6 sec, for basin. The total volume of DHW system consists of 0.99 L in pipes and 1.1 L in HEX (type XB37H-40). It means, that it is possible to install longer pipes or more fixtures and still fulfil requirement of DHW system with volume lower than 3 L. The velocity of flowing water is below 2 m/s and thus problems with noise propagation during tapping are avoided.

Table 1 – Transport delay for nominal flows for individual fixtures due to DS439, in DHW system in typical house in Lystrup, for pipes with inner diameter 10 mm

fixture	nominal flow (L/min)	length to fixture (m)	volume in pipes (L)	velocity (m/s)	transp. delay (s)
shower	8.4	2.2	0.17	1.8	1.2
basin	3.4	4.1	0.32	0.7	5.8
kitchen	6	6.3	0.49	1.3	4.9

Tap delay on primary side

A transport delay on primary side consists of delay in branch pipe and delay in DH substation. While tap delay in DHW installations in building is for DHW system without circulation uniquely determined, tap delay on primary side varying as control strategies for substation control varies. From energy consumption point of view, the best solution is a control strategy without by-pass (see Fig. 1). In this case, DH water staying in the branch pipes is cooled down to temperature of ambient ground (if tapping wasn't performed for long time) and DH water in substation to room temperature. In general, waiting time for DHW is influenced by controller used in substation. Basic principles of controllers are proportional flow controller and thermostatic controller. Each controller has own advantages and disadvantages, thus best solution is to combine both controllers [12]. In case of proportional flow controller, ratio between primary and secondary flow is fixed to provide DHW with desired temperature and it means in case of using LEDH primary and secondary flow will be very similar. If proportional flow controller is used for setup without by-pass, user will face long waiting time for DHW. Waiting time for this case can be seen from Table 2. For branch pipe with inner diameter 15 mm (as is designed in Lystrup for IHEU), even transport delay to reach substation for nominal flow for basin, kitchen sink and shower will be 31.6, 17.7 and 12.6 sec, respectively. This solution is from comfort point of view and water savings completely unacceptable. If we decrease inner diameter of branch pipe to 10 mm, transport delay is decreased roughly to one half of value for pipe with inner diameter 15 mm, but it is still long time. In case of combined proportional flow controller and thermostatic controller, from beginning of tapping thermostatic part assures opening of valve on approximately full capacity until desired temperature of DHW is reached.

Table 2 – Transport delay for nominal flows for individual fixtures due to DS439, in branch pipe, 10 m long, for typical house in Lystrup, data simulate using proportional flow controller without by-pass

fixture	nom. .flow (L/min)	inner pipe Ød (mm)	volume in pipes (L)	velocity (m/s)	transp. delay (s)
basin	3.4	15	1.77	0.3	31.6
kitchen	6	15	1.77	0.6	17.7
shower	8.4	10	0.79	1.8	5.6
shower	8.4	15	1.77	0.8	12.6
bath	12.6	15	1.77	1.2	8.4

Full opening from beginning of tapping leads to much higher flow rate on primary side than on secondary and time delay is decreased substantially. This solution can be used for short branch pipes with reduced diameters. But it should be mentioned, that transport time in branch pipe will be always limited by maximal allowed flow on primary side defined by DH provider by means of flow restrictor or by available differential pressure in DH network. To reduce tap delay on primary side, control concepts with by-pass, avoiding cooling of DH water in branch pipes and substations, and thus reducing substantially waiting time for DHW are available. There are two concepts of by-pass in relation to the heat exchanger: external and internal by-pass (see Fig. 1). In case of external by-pass, DH water enters substation, but not enters heat exchanger and is sent back to DH return pipe and thus branch pipe is kept on desired temperature. Desired temperature is controlled by thermostatic valve situated in by-pass loop. Increased level of comfort expressed by reduced tap delay can be adjusted independently on temperature of DHW on secondary side.

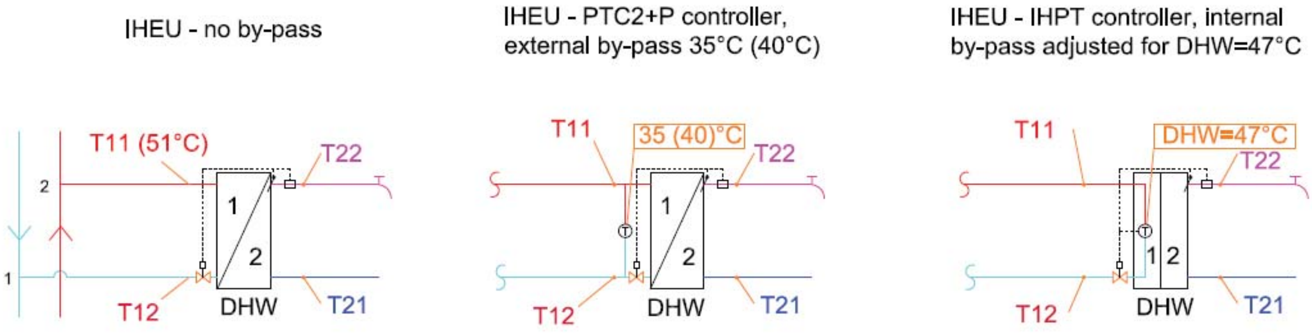

Fig. 1 Different by-pass strategies for IHEU: left - no-by pass; middle - external by-pass (cold HEX); right - internal by-pass (hot HEX)

The set-point temperature of external by-pass is always compromise between insufficient cooling of DH water and additional heat consumed by customer and reduced waiting time for DHW. In case of operation of space heating system, the function of by-pass is to some extend overtaken by space heating loop and thus heat for “by-pass” operation is not wasted and temperature of DH water returning to DH network is cooled sufficiently..In case of internal by-pass, by-pass flow is passing through heat exchanger and keep it warm (see Fig. 1). The benefit of this solution is even more reduced tap delay than in case of external by-pass, but on the other hand, since heat exchanger is kept warm, internal by-pass solution has additional heat losses. If substation is installed in room with need of space heating, heat losses are considered only outside of heating season.

Contrary to external by-pass solution, where it is not so important if space heating loop is installed in series or in parallel to DHW heat exchanger, in case of internal by-pass it is in importance. If space heating loop is connected in parallel to DHW heat exchanger in traditional way, by-pass water just pass through DHW heat exchanger and is sent back to DH network with still high return temperature, without any other use. If space heating loop is connected in series to DHW heat exchanger or in parallel but with possibility to sent by-pass water flown through internal by-pass to space heating loop (see Fig. 2), this solution provides high level of comfort for users as well as proper use of heat needed for by-pass operation.

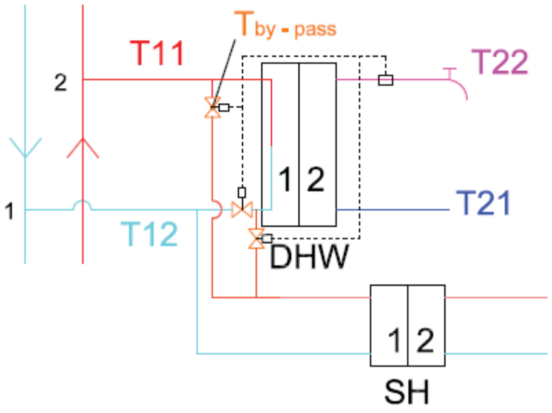

Fig. 2 Combined by-pass concept, with possibility of use by-pass flow in space heating loop

In order to run by-pass without drawback of insufficient cooling of DH water and wasted heat also outside of heating season, it is proposed to use by-pass flow for floor heating, installed in bathroom and operate it all year. From preliminary calculations it looks, that flow needed to keep bathroom floor surface temperature on 24°C will be enough as by-pass flow. Considering the use of renewable sources of heat, the problem of insufficiently cooled DH water is related to reduced efficiency of these sources and whole year using of floor heating for comfort in bathroom is reasonable.

Supply – supply recirculation

As an alternative solution for customers who don’t want to use whole year bathroom floor heating, solution called supply-supply recirculation is a possibility how to use benefits of by-pass without whole year heating of bathroom. In this case, district heating water is supplied by pipe 1 to substation, circulated through HEX or external by-pass (see Fig. 3) and then sent back to district heating network (DHN) supply by pipe no.3. This concept is in early stage of investigation but it looks promising. The main question will be related to flow of DH water in branch pipe in order not cool it down too much before will be sent back to DH supply pipe in the street.

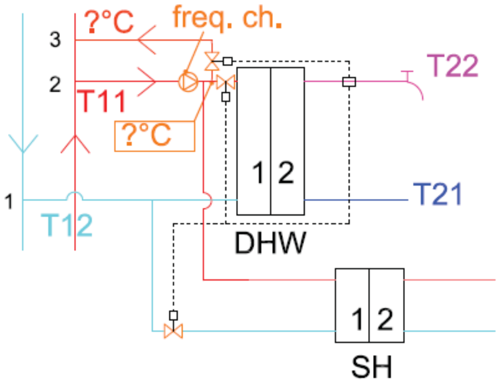

Fig. 3 Supply – supply recirculation with external by-pass

This solution is expected to be favourable mainly for circular shapes of DH networks, but it should be mentioned, that re-heating stations will be probably needed in point of DH network, where temperature of DH water decrease bellow defined value.

Full scale demonstration of LEDH

Full scale demonstration of LEDH is recently running in Larch Garden in Lystrup, Denmark [11], where 40 low energy houses class 1 and 2 are connected to LEDH system, with designed forward temperature from heat plant 52 °C. For primary side of substation, forward temperature of 50 °C and return temperature of 25 °C are designed. The DH network is built from highly insulated single pipes (for main pipes) and main pipes with smaller diameter, distribution and branch pipes are built from twin pipes. Two types of district heating substations providing houses with DHW and space heating are tested by customers in real conditions. The first concept is 29 Instantaneous Heat Exchanger Units (IHEU), second is 11 District Heating Water Units (DHWU). IHEU is classical concept of substation with instantaneous heat exchanger, only with enlarged number of plates. IHEU units have external by-pas, with set point temperature of 35 °C for customers situated not at the end of street and 40 °C for customers situated at the end of the street. DHWU is new concept of DH substation, reported e.g. by Paulsen [13]. DHWU consist of buffer tank for district heating water and when DHW is needed, DHW is heated in instantaneous heat exchanger as in previous case. Advantage of concept with buffer tank is peak-shaved demand of DH water during charging and use of branch pipes with lower diameter, connected with lower heat loss. On site measurements were started in Lystrup to evaluate performance of both types of DH substations, but no detailed measurements requiring short time steps are performed to evaluate level of users comfort. The measurements more focused to user's comfort are planed to be performed this year in Danish Technological Institute and Technical University of Denmark (DTU) on DH systems simulating the conditions in Lystrup. The DH systems will consist of branch pipes, substation and DHW building installations and different control approaches (external or internal by-pass, different set up by-pass temperatures, possibility of supply-supply recirculation, etc.) will be studied for DH substations supplied by LEDH. Measured data will be used for evaluation of performance of different control concepts, level of users comfort and lately also for validation of numerical model which is aimed to be developed for optimization LEDH systems.

TEST OF TEMPERATURE PERFORMANCE

As a first part of measurements planed to be performed at DTU, the time needed for IHEU to produce DHW with temperature of 42 °C and 47 °C was measured, after tapping of DHW was started. The tap delay was investigated for two control strategies, one using internal and second using external by-pass. The measurements were performed for different initial conditions before tapping was started to simulate in realistic way users behaviour. Finally, the period between two by-pass flow operations was measured.

Experimental setup and instruments

Tested DH substation was prototype of Instantaneous Heat Exchanger Unit (IHEU) developed specially for LEDH pilot project in Larch Garden – Lystrup, Denmark. The IHEU is a type of district heating substation consists of a heat exchanger (HEX) without storage tank. DHW is heated instantaneously in HEX only when tapping is performed and then supplied directly to DHW taps by individual feeding pipes, while space heating is using direct connection without heat exchanger, i.e. concept typical for Denmark. Substation is same concept as regular IHEU for traditional DH. The difference is in increased number of plates in heat exchanger assuring better heat transfer. Water volume of primary and secondary side is 1.1 L each and the heat exchanger is not insulated. The experiments were focused only on dynamic behaviour of substation related to DHW heating and thus space heating loop wasn't connected and space heating valves in substation closed. Desired temperatures of DHW were chosen in accordance with requirements in DS439 for temperature of DHW for kitchen sink and other fixtures. Required temperatures mentioned in DS 439 are 45 °C and 40 °C. In order to cover additional temperature drop in building DHW installations, 2 °C were added. This addition is based on experience from previous measurements. During the experiments, temperatures of four different flows passing through the DH substation were measured. On primary side it was temperature of DH water supplied to substation (T11) and temperature of DH water returning back to DH network (T12) and on secondary side it was temperature of cold potable water entering substation (T21) and temperature of heated DHW (T22). All temperatures were measured by thermocouples type T, installed directly in pipes, in flowing water, so they do not have any practical time delay for the measurements. The time constant to reach 90% of step change was less than 1 second. The distance of thermocouples from substation flanges was 5 cm and thermocouples were previously calibrated. We also measured surface temperature of HEX in upper (HEX-UP) and bottom part (HEX-DOWN) and temperature of air in the testing room. Temperatures were measured and collected by multifunction acquisition unit every second. For authentic simulation of DH network, DH water with constant temperature of 51 °C was necessary. It was solved by connecting of IHEU to source of DHW in laboratory of DTU, where DHW is supplied by DH system. DHW system of DTU is big enough, to assure stable temperature 51 °C without any fluctuations. In order to prevent cooling down of pipes supplying DHW to laboratory in periods when there was not flow through substation (stopped by by-pass controller), small guard flow, just before entrance to substations was kept to maintain DHW always on 51 °C and drained to sink.

Experimental procedure

As a first step, both controllers were adjusted to provide 47 °C on DHW side with supply temperature of DH water 51 °C. Then we measured time delay in the substation, i.e. time needed for substation to produce DHW with temperature 42 °C and 47 °C on secondary side outlet from the moment when DHW tap is opened.

The measurements were performed for different initial conditions and secondary flowrate was always 8.4 L/min, which is nominal flow for shower.

1. For measurements of concept with external by-pass, substation was controlled by PTC2+P controller with by-pass set point temperature adjusted to 35 °C. This setup is exactly the same as is installed in Lystrup pilot project. The testing procedure was made in following steps. Substation was left idle for long time in the testing room, so all components and water in HEX were on room temperature. Than we opened the valve on DH supply in substation and DH water with temperature of 51 °C started to flow in the substation and flew through external by-pass, until closing temperature was reached and by-pass flow stopped. Then we wait until by-pass was opened again. Time between two by-pass openings as well as volume and temperature of DH water passed through by-pass was written down and after by-pass was closed again, we waited a little bit shorter time than was needed to open by-pass flow again and we start tapping on secondary side with flow rate 8.4 L/min. In this way, most unfavourable condition for substation with by-pass, i.e. highest recovery time, was measured. After tapping of DHW was finished, we wait 5 minutes and we performed one more tapping to simulate short time step between two subsequent tapping of DHW.

2. For measurement of internal bypass concept, IHPT controller was used. In case of IHPT, by-pass set point temperature can't be adjusted independently and is defined by desired temperature of DHW, i.e. 47 °C for our measurements. IHPT controller was developed for traditional DH networks operating with forward temperatures around 70 °C. For traditional DH, by-pass opens when temperature in HEX falls 5–7 °C below set point of DHW, but in case of LEDH with forward temperature 51 °C, by-pass opens 1 °C below DHW set point temperature, i.e. 46 °C in our case.

The testing procedure was similar to measurements with external by-pass. After supply valve on primary side of substation was opened, DH water with temperature of 51 °C started to flow in the substation and temper HEX, until by-pass closing temperature was reached. Then we wait until by-pass was opened again and we performed tapping of DHW just before next by-pass opening was expected. In following steps was procedure same as in case of external by-pass.

Moreover, we also performed measurements of time delay in IHEU for control concept without by-pass.

RESULTS

Time delay for IHEU with PTC2+P controller and external by-pass adjusted to 35 °C to start supply DHW water with temperature 42 °C and 47 °C after long idling period just before opening of external by-pass was expected, can be seen from Fig. 4 and is 11 and 22 seconds, respectively. This measurement represents condition with the longest time delay for PTC2+P controller. Temperature of room, where IHEU was installed was 22.2 °C. For this case, temperatures of produced DHW in first 10 sec after tapping was started are listed in Table 3.

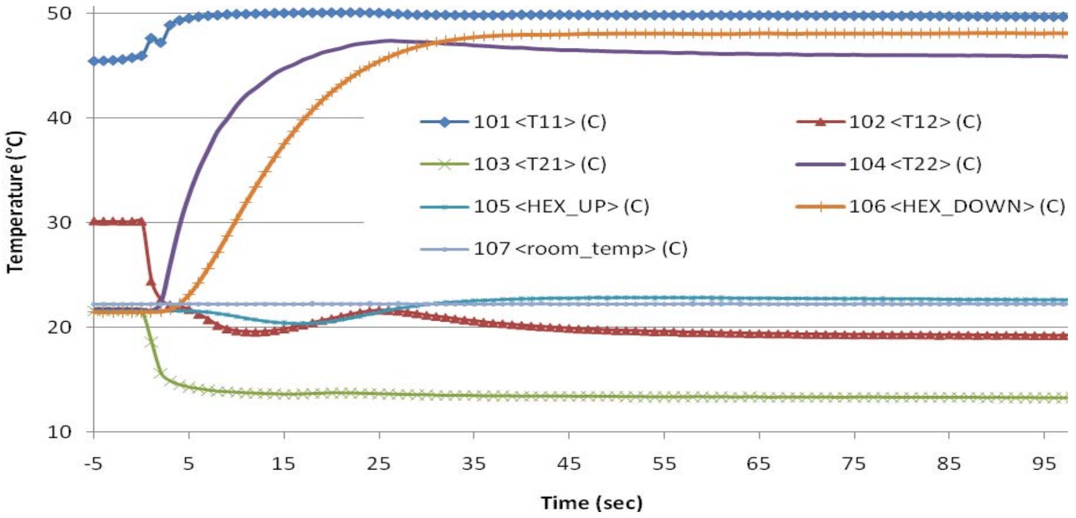

Fig. 4 Time delay for external bypass (PTC2+P), when tapping is performed just before expected start of by-pass flow, set on 35 °C.

In case, when tapping of DHW was performed after long idling just after by-pass flow was stopped, time delay decreased to 8,5 and 16,5 seconds. In this measurement, temperature of substation and thus water standing in the HEX was little higher than ambient air temperature. It is expected that time delay will be slightly longer, if substation will have real ambient temperature but still shorter than in case 2. We also performed measurement of tap delay five minutes after previous DHW tapping was finished. In this case, tap delay in substation to produce DHW with temperature 42 °C and 47 °C was shorter, 7 and 14 seconds.

For room temperature around 22 °C, external by-pass was opened roughly every 30 minutes. The by-pass was in average opened 2.5 minute and volume of DH water needed to close the by-pass was in average 3 L, i.e. when substation is idle, by-pass uses 6 L of DH water per hour.

Table 3 – Temperatures measured for PTC2+P controller in first 10 sec after tapping was started for situation after long idling, just before by-pass was expected to run again

τ(sec)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
T22 (°C)	21.6	22.3	26.0	29.7	32.6	35.0	36.9	38.7	39.9	41.2	42.2	42.8	43.5	44.2	44.7	45.1	45.5

Time delay in IHEU equipped with IHPT controller with internal by-pass adjusted by requirement of DHW to 47 °C was 6 and 14 seconds to reach 42 °C and 47 °C on outlet for situation when tapping was performed just before by-pass was expected to open. The internal by-pass opens 3 minutes after previous tapping is finished and when is once opened never closes, only when another tapping is performed, but again only on 3 minutes.

The average flow of internal by-pass was 24 L/hour and average return temperature to DH network was 45 °C. When internal by-pass is once opened, the time delay in substation decrease substantially to 1.5 and 7 seconds to produce DHW with temperature 42 °C and 47 °C. The condition with expected longest time delay was solution without by pass. In this case time delay to produce DHW with temperature 42 °C and 47 °C was 12 and 25 sec. All measured results are summarized in Table 4.

Table 4 – Overview of time delays for all measured cases

	case number and description	**T_{11} (°C)**	**τ_{42} (sec)**	**τ_{45} (sec)**	**τ_{47} (sec)**	**T_{12} (°C)**	**T_{12AVG} (°C)**	**T_{HEX-UP} (°C)**	**$T_{HEX-DOWN}$ (°C)**
NO BY PASS	1 – after long idling, no by-pass (BYP)	50.1	12	18	25	16.2	19.5	20.4	21
EXTERNAL BY-PASS	2 – after long idling, just before BYP was expected to open again	49.6	11	16	22	30.1	19.3	21.5	21.4
	3 – after long idling, just after BYP closed	50.6	8.5	12	16.5	42.6	19	*29*	*26*
	4 – 5 minutes after previous tapping finished	50.8	7	10	14	25	19.1	22.3	37.4
INTERNAL BY-PASS	5 – just before BYP was expected to open (3 min after prev. tapp. finished))	50.5	6	10	14	19.5	19.1	22.6	38
	6 – anytime, when BYP was already in operation	49.3	1.5	3.5	7	47.3	18.4	44	45.5

DISCUSSION

Focused on level of users comfort and proper cooling of DH water during idling, time delay of LEDH substation to supply DHW with temperature 42 °C and 47 °C was measured. Three different control strategies related to tap delay were investigated. Obtained results represent case of IHEU used in single-family house in period when space heating is not in operation. Explored concepts can be evaluated from two different points of view, due to highest advantages for customer and for DHN.

The solution without by-pass is from energy savings point of view very interesting because doesn't need any DH water for idling, but from users comfort point of view is very poor because of reduced comfort and problems with wasting of water during waiting for DHW with desired temperature. Solution without by-pass can be probably used for substations equipped with combined thermostatic and proportional flow controller, for customers with short branch pipes or for customers with low requirements for level of users comfort. If solution without by-pass will be used for substation controlled only with proportional flow controller, even transport delay in 10 m long branch pipe for nominal flow for basin will be 32 sec. For period when space heating is operated, branch pipe will be kept warm from flow needed for space heating and time delay for solution without by-pass will be very similar to solution with external by-pass. Anyway, in non-circularly shaped DH networks, by-pass should be installed at least at the end of a street, so it is better to find solution how to use by-pass flow in useful way than sent it directly back to DH return. Considering this, it is suggested to use by-pass flow for whole year operation of floor heating in bathrooms to increase comfort for customers and at the same time solve problem with by-pass flow which otherwise increasing return temperature to DH network.

From user comfort point of view, better solution than solution without by-pass, but consuming more energy, is substation equipped with external by-pass. By comparison of results of concepts without by-pass (case 1) and solution with external by-pass, for case when tapping is performed after long period of idling just before by-pass opens again (case 2), we can see that time delays are almost the same (see Table 4). Difference is only that for external by-pass are pipes in DH substation kept on higher temperature and it made slightly faster reaction. In the case 3, time delay is even more reduced since pipes in substation were warmer by just finished by-pass flow. For control concept with external by-pass and tapping repeated 5 minutes after previous one, time delay is again reduced, since HEX is still hot from previous tapping. The time delay for case 4 and 5 are almost the same, only difference is that in case 5 (internal by-pass), tap delay is again reduced because tapping was performed 3 minutes after previous (to prevent influence of by-pass) and thus HEX was warmer.

If the requirement is to fulfil 10 sec tap delay for less favourable fixture, i.e. in our case basin (see Table 1), DHW should leave DH substation with temperature 42 °C in 4 sec after tapping was started, because it will take 6 second to reach the tap. This requirement was reached only by concept with internal by-pass and only when by-pass was already opened. On the other hand from Table 3can be seen, that even for concept with external by-pass and tapping after long idling and just before expected bypass opening, DHW at a temperature 26 °C leaving substation in 3 sec. DHW with this temperature is not sufficient for taking a comfortable shower for which temperature 37±1 °C is preferred, but for washing hands this temperature should be enough. The values in Table 3 are for flow rate used for shower, but it can be used to explain that it is time to rethink the suggested value of tap delay from 10 sec to another value and consider also nominal flows and use of tapped water. The different standards for the different use of DHW based on new solutions in DHW supply systems and results from test panels are needed, because it may have some influence on design of optimized DHW systems. Nevertheless, for customers requiring DHW in very short time e.g. continuously or discontinuously (only during rush hours) operated trace heating elements can assure almost no tap delay by keeping DHW staying in pipes on desired temperature.

CONCLUSION

Based on literature study it can be concluded that hygienic requirement of DHW with 50 °C on outlet of DHW heater is not needed for systems with a total volume of the DHW lower than 3 L.

From results of our measurements and evaluation of IHEU supplied by LEDH, only substation with external by-pass with set point 46 °C is able to produce 47 °C DHW in time bellow 10 sec. The easiest step how to decrease waiting time also for other concepts is to insulate HEX. This measure will reduce time delay for DHW tapping and also will decrease heat losses from DH substation. The lower waiting times for DHW can be also achieved by further optimisation of HEX in way of decreased number of plates reducing volume of water in HEX and thus transport delay, and by increased thermal efficiency of HEX (followed on the other hand by higher pressure loss). These modifications can lead for higher temperature of DH water returning to DH network, but during all our experiments, average return temperature was below 20 °C, what is 5 °C less than is designed for LEDH.

Traditional control concepts of DH substations are always trade-off between users comfort and reduced cooling of DH water during idling and thus customer should have to some extent possibility to choose which solution prefers. In case of traditional concepts, decision is between longer waiting time for DHW and energy savings or vice versa, if by-pass in substation is used. In non-circularly shaped networks, by-pass should be used anyway at least at the end of a street line. The one of possible solutions how use by-pass flow in better way can be proposed innovative concept of whole year operated floor heating in bathrooms or supply-supply recirculation. Both solutions will increase level of user comfort and at the same time also energy efficiency of DH system.

LEDH is a promising solution for providing buildings with DHW and space heating regarding fulfilling requirements of modern society with reduced CO_2 emissions and energy consumption. More detailed investigations by testing of different parameters and numerical simulations are needed in order to optimize LEDH concept.

Future work

It will be very interesting to compare time delay of substation for traditional DH with time delay for DHW produced by LEDH substation. It is expected that timed delay for LEDH will be higher because dynamic response is slowed down by lower temperature difference between DH water and desired temperature of DHW, but on the other hand, lower temperature difference is in some extend compensated by bigger HEX. It is also suggested to rethink “10 sec tap delay suggestion” for different taping flows and purposes of DHW use.

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