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EXPIERIENCES ON LOW-TEMPERATURE DISTRICT HEATING IN LYSTRUP – DENMARK

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ABSTRACT

This paper includes main findings made during the Danish governmentally founded project “Development and Demonstration of Low-Energy District Heating for Low-Energy Buildings”, EFP2007, and the Danish governmentally founded project ”CO2-reductions in Low-Energy Buildings and Communities by implementing Low-temperature district heating systems. Demonstration cases in EnergyFlexHouse and Boligforeningen Ringgården” EUDP 2011.

A key challenge for optimum and competitive district heating (DH) system operation is reducing heat loss in networks. Today building regulations in most countries demand reduction of heat consumption for individual buildings. This means ratio between net work heat loss and heat consumption in buildings will become even more important in future. To address this challenge low-temperature DH network concept is analysed and tested in real scale.

This paper describes main findings in relation to low-temperature DH unit concepts, operational experience with the system, including 41 low-energy apartments and energy losses realised in distribution. This also includes findings in relation to domestic hot water simultaneous factors and users’ comfort.

Key Words: Energy efficiency, Low-temperature District Heating, Laboratory measurements, field measurements, simultaneous factors, distribution energy loss, user comfort

1. INTRODUCTION

Energy demand and environmental impact caused by using fossil fuels are growing worldwide. Roughly 40% of all energy is consumed in building stock and thus reduction of energy in building sector is one of the main issues in future. EU energy policy is focused on energy savings, security of supply and fossil-free future. Denmark aims at 100% renewable energy sources in 2050. DH is one of the solutions how to achieve these goals. Well-known advantage of DH is possibly to use surplus heat from industrial processes and waste incineration which otherwise will be lost. The incineration of unrecyclable waste in CHP is the best known solution how to process increasing volume of communal waste, and in Denmark it covers 20% of heat demand for DH. Requirements to energy performance of buildings are introduced generally. Heat demand of buildings is decreased by applying improved building envelopes and more efficient heat recovery for ventilation systems, and thus heat losses from DH network become a key issue for DH in future. A way to achieve reduced heat loss from DH network is to reduce supply temperature as much as possible, i.e. use Low-temperature DH (LTDH). LTDH system usually means DH system with a supply temperature of 65°C, but our concept goes even further, i.e. a supply water temperature slightly above 50°C. Reduced temperature level results in many benefits as reduced heat losses from DH network, but also challenges connected mainly with domestic hot water (DHW) preparation. In addition, lowered temperature level makes it possible to exploit renewable sources of energy with higher efficiency and thus easier introduces more fossil-free sources. In general, renewable energy sources as heat pumps or solar thermal collectors are more efficient when operating in bigger scale, and harvested heat is distributed by DH systems to individual users compared to small individual sources. Moreover, seasonal heat storage can be used in case of collective solution and can improve annual efficiency [1].

This paper reports results gained during development and demonstration of low-temperature district heating (LTDH) concept for new low-energy single-family houses in Lystrup, Denmark. As a next step optimization of LTDH concept for existing buildings will be investigated, since these buildings represents majority of existing building stock. Moreover, in many European countries DH is main or one of the main solutions for heat delivery for buildings in cities. The project focused on existing buildings has already been granted by Danish government and will be started in early 2011 [2].

2. DEMONSTRATION SITE FOR LOW-TEMPERATURE DISTRICT HEATING

The progressive Danish housing association ‘Boligforeningen Ringgården’ has during the recent years built a number of new low-energy buildings and chose for a new project in Lystrup, Denmark, low-temperature district heating as heat supply. The project in Lystrup involves 7 row houses with totally 41 apartments. Two sizes of apartments are available: 89 m^2 and 109m^2 (gross area) with design heat demands for space heating of 2.2 kW and 2.6 kW respectively. All rooms - except bathrooms - have low-temperature radiators that are designed for flow temperature of 55°C and return temperature of 25°C – the bathrooms are supplied with floor heating. District heating water is supplied directly with no heat exchanger between building heating system and district heating system.

Two different types of district heating substations developed especially for supply temperature slightly above 50°C are installed in the apartments. The substations are characterized by producing DHW with a plate heat exchanger (instantaneous water heater), but are based on some very different principles. One type has a 120 liter storage tank on the primary side (district heating side) and is designed for equalizing the load over time in order to be able to reduce supply pipes dimensions as much as possible – this is called the storage tank unit (STU). The second type is a more traditional heat exchanger unit (HEU) with normal load requirements.

All apartments have district heating meters installed, but in order to compare the 2 principles, 11 STU's and 11 HEU's were also equipped with heat meters on the DHW side and with room temperature sensors in the living rooms. The meters are all connected to a M-bus system which makes it possible to make data acquisition on minute level.

The first tenants moved into the apartments in the beginning of 2010 and data acquisition started end of June. The results presented in this article are based on data collected from June to December 2010 (week 26-47).

3. DISTRICT HEATING NETWORK

District heating network is designed according to the 'low-energy district heating for low-energy buildings' concept presented in [3]. A sketch of the network is shown in figure 1. The local district heating utility, 'Lystrup fjernvarme', is supplying heat to a central spot (yellow lines) where a mixing shunt is lowering the supply temperature to about 55°C and a booster pump is raising the pressure dependent on the available pressure difference at the critical consumer (green circle) in the distribution network (black lines).

Low flow temperature and low consumer heat consumption is challenging the supply pipe system. Had traditional network design philosophy and pipe design been used, the relative energy loss would have been unacceptable.

Pipe design chosen is Alu-flex twin pipes in as small dimensions as possible utilising the available head loss. The service pipes are multilayer pipes with an inner layer of PE-X, a load bearing intermediate layer of aluminium and an outer layer of PE-RT. The advantage of this choice compared to others is that any exchange of insulation gas or water vapour between the heating water and the insulation material is excluded. For house entries a new media pipe dimension of only 14mm outside diameter was developed for the project. Insulation material is ultra fine cell PUR foam expanded with Cyclopentane (CP). Heat conductivity (λ) of the material is 0,022W/mK at 50°C. The outer casing is a thin-walled LLDPE with an integrated aluminium diffusion barrier. The diffusion barrier, together with the aluminium layer in the service pipe, effectively prevents the ageing of the insulation capacity well-known from traditional pipe design. The Alu-flex twin pipes were delivered in coils up to 100m length.

Booster pump energy consumption, overall district heating consumption and outdoor temperature is measured at the central spot. Furthermore additional heat meters are installed at strategic places in the network in order to measure heat losses and compare 11 STU's and 11 HEU's.

Figure 1 The basic DH net lay out

4. ENERGY CONSUMPTION OF BUILDINGS AND NETWORK LOSSES

Buildings and network have not yet been in operation for a full year, but results are very promising. After some start-up problems the system is now operating as intended and heat loss of network is generally as expected. Based on 5 months' measurements, energy signatures of heat load and pump operation have been developed. With input from network heat loss and reference climate data an annual calculation was carried out. Calculation shows an annual energy consumption of all buildings of 238 MWh and a heat loss of 49 MWh. In relation to the energy used this is a network heat loss of only 17%. Had the network been designed with traditional single pipes and a supply temperature of 80°C and return temperature of 40°C, the heat losses would have been about 4 times higher in terms of energy, which would not have been acceptable.

5. SIMULTANITY FACTORS

Energy loss of DH network is, besides the media temperature and degree of insulation, dependent on media pipe size, since heat loss is linked to the area in contact with the hot medium. To determine media pipe dimensions for a group of consumers, a good model for the group load of DHW and heating is a precondition for energy efficient design. Quite a lot of work is done in this respect, see [4], anyhow typically based on one family house where the load is expected to be higher than for the Lystrup site. A part of this project focuses on the group loads measured at Lystrup site. The measuring period was during summer from week 24 to week 38 year 2010, when no or only limited heating was used for bath room floor heating. The group load is based on 1 to 10 apartments with a HEU and 1 to 10 apartments with a STU, [5]. Meters used are sampling once pr. 4 minutes. This is not that tight, but if the total numbers of samples are high enough, a representative statistic result will be obtained. In total approx. 38.000 samples are made for each apartment. Flow is calculated as 10 sec. average value, and temperatures are momentary measurements. Due to short integration time for flow calculation, it is assumed that integrated flow values represent the maximum momentary flow, since the tapings typically are much longer than 10 sec.

For this project, Danish code of practice for water installations [6] was used for dimensioning DHW consumption for HEU and STU. It states for a HEU in a one family house without bath, dimensioning of DHW draw off power is 32.3 kW. During measuring period maximal draw off was measured to:

HEU max. power one apartment e(1) = 26 kW, max. flow q(1) = 850 l/hr
HEU max. power 10 apartments e(10) = 37 kW, max. flow q(10) = 1080 l/hr

It can be seen that these values are quite below recommendations applied by Danish code of practice. Looking at the STU then results were:

STU max power one apartment e(1) = 10 kW, max. flow q(1) = 320 l/hr
STU max power 10 apartments e(10) = 17.5 kW, max. flow q(10) = 790 l/hr

The values for STU are too high and partly are a result of poor adjusted controllers. The goal was to have maximum primary load from DHW of 100 l/hr pr. consumer for DHW preparation.

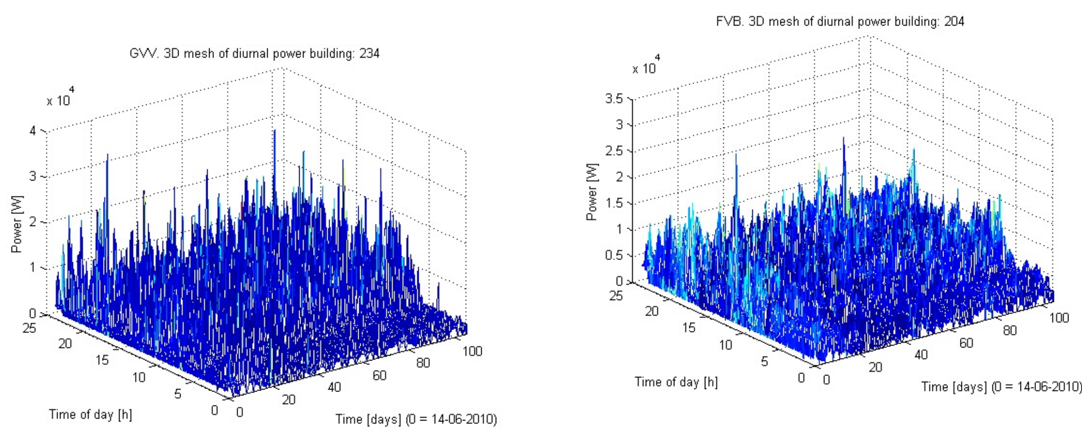


Figure 2 LEFT - HEU Power for 10 apartments as function of time of the day and the day, RIGHT – STU Power for 10 apartments as function of time of the day and the day.

Looking at figure 2, it can be seen that maximum values are only represented rarely. Using maximum measured values will give unnecessarily high design group values. It will be similar to design a main road without any waiting time for cars at any time at all. In this analysis it is accepted that in 1% of samples, on condition that there is a DHW tapping, actual group load value exceeds design value. 1% value corresponds to approx. 15 minutes pr. day where design load can be expected to be exceeded, but only if tapping takes place all 24 hr. In reality tapping via HEU or charging of STU has much less duration pr. day and, therefore, also the period will be less than 15 minutes.

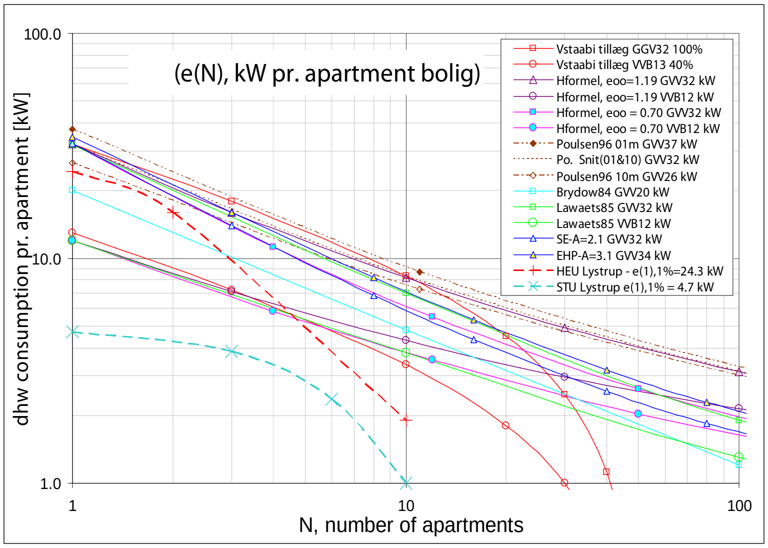


Figure 3 Simultanity curves for STU and HEU measured at Lystrup site compared to earlier works

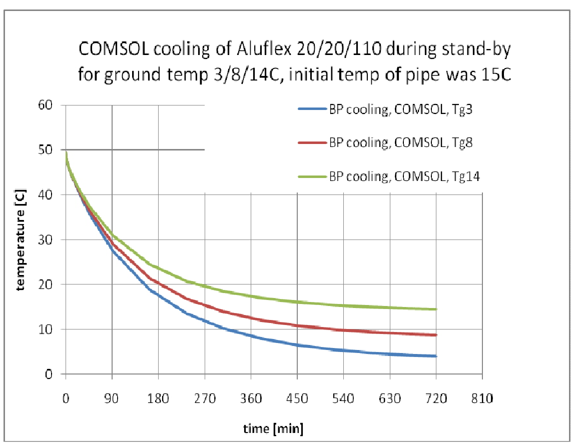
Figure 3 shows that for HEU the curve is parallel up to 2 apartments compared to earlier works. For a higher number of apartments the curve is decreasing considerably faster, basically with the slope -1, meaning no coincidence between a higher number of apartments. This is a result of smaller and rather rare DHW tapings. For STU a more evident coincidence is seen up to approx. 6 apartments. For more than 6 apartments also here a fast decreasing curve can be seen. In general, level of curve for STU could even be lower, since some of the flow limiting valves where not set properly during test. Target is a maximum flow of 100 l/hr for charging corresponding to approx. 3.5 kW. This adjustment will also automatically result in a higher degree of coincidence for the high number of apartments.

6. COMFORT ON DOMESTIC HOT WATER

In comparison with existing buildings, heat demand for space heating (SH) is with improving building shell and heat recovery for ventilation systems still decreasing, but need for DHW remains the same if we do not consider water saving caused by its increasing price and growing environmental awareness. In order to spread widely LTDH concept, it must provide high level of comfort for users while keep low-energy consumption. In case of DHW comfort is expressed by waiting time for DHW with desired water temperature and its temperature stability. Due to recent Danish code of practice for DHW, temperature of DHW delivered to tap should at least be 45°C delivered in 10 sec after tapping with flow rate 0.2 L/s started, but this requirement is recently being discussed [7]. Temperature stability is usually not a problem, so we focus on waiting time for DHW. Waiting time for DHW consists of delay on primary side, i.e. in the branch pipe, in the substation and on the secondary side, meaning DHW feeding pipes supplying individual fixtures in the house. Waiting time depends on type of DH substation (SUB). Since SUB are supplied with DH with supply temperature slightly above 50°C, traditional storage tank for DHW cannot be used because of Legionella risk. Anyway, storage tank concept gives some benefits, e.g. no need of by-pass for lower waiting time for DHW, or lower heat losses from the branch pipe (BP). These benefits are presented in STU storing DH water instead of DHW developed by [5] and are tested in Lystrup. Both SUB types use instantaneous principle of DHW preparation, i.e. immediate distribution of DHW to the DHW system. While in case of STU the DH water is usually available from beginning of DHW tapping drawn from primary storage tank and thus almost immediately available in heat exchanger (HEX), in case of HEU the transportation time of DH water with design temperature 50°C to HEX depends on by-pass set-point temperature (in Lystrup it is 40°C for last consumer in the street and 35°C for others) and period passed from last DHW tapping. During heating season is function of by-pass overtaken by space heating system.

Since LTDH wants to be a highly energy efficient concept, DHW circulation (DHWC) system is not used. DHWC is meant to reduce waiting time for DHW in farther taps, and in bigger DHW systems it is also used for control over Legionella issue. Main reason for not using DHWC is relatively high energy loss and moreover because of Legionella problems. A return temperature from circulation above 50°C, which cannot be fulfilled by LTDH, should normally be guaranteed. The solution is to make DHW distribution pipes in houses as short as possible, i.e. rooms with DHW taps should be concentrated close to the technical room with SUB. This idea is very important to be accepted and used by architects when designing new buildings. For multi-storey buildings the solution is in individual SUB for each flat so called flat stations [7].

Since DHWC is not used, tap delay in DHW feeding pipes is defined by its length, inner diameter and period passed from last DHW tapping. It means that reaction time for HEX to produce DHW water with desired temperature becomes very important. Based on the laboratory measurements of HEX used in both SUB, SUB with HEX cooled down to room temperature needs around 12 sec to produce DHW with temperature of 42°C after 50°C hot DH water arrives to the border of SUB. This time delay is reduced to 7 sec when previous tapping was finished 5 minutes before actual tapping. It documents, that SUB alone has considerable recovery time and thus additional delays on primary and secondary side of HEX should be limited as much as possible.



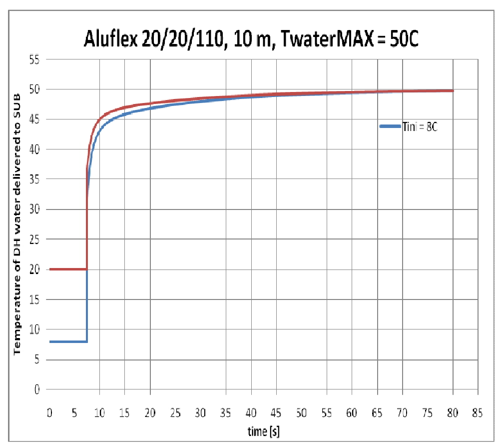


Figure 4 LEFT – cooling of water standing in branch pipe during idling,
RIGHT – influence of themral capacity of branch pipe on cooling of supplied water

Transport delay in BP is critical only for HEU concept. Figure 4-LEFT shows cooling down of DH water in BP during stand-by calculated for Aluflex 20/20/110 by COMSOL Multiphysics software. It appears that outside heating period, with average ground temperature of 8°C, branch pipe for HEU without external by-pass will be cooled down to

20°C aproximatelly after 180 minutes of idling. When DHW tapping is performed after idling, first cooled water in the BP should be passed through HEX and after that the HEX is supplied with DH water with design temperature of 50°C. Additionally to transport delay an influence of branch pipe's thermal capacity should also be added. For example for already mentioned 10 m long Aluflex 20/20/110 filled with water with 20°C and ground temperature of 8°C pure transportation time counts for 7.5 sec but first water supplied to HEX is by thermal capacity of branch pipe cooled down to 37°C (see Figure 4-RIGHT). It takes another 2.5 sec to deliver 45°C water and 55 sec to deliver 49.8°C. This example documents that outside the heating period and without operation of by-pass, 10 sec in DHW preparation can easily be lost just on primary side, than 12 sec in SUB and depending on length of feedings pipes and flow-rate of DHW additional delay on secondary side is added. Waiting time for DHW is mainly unpleasant for showering. In Lystrup shower is placed immediately next to SUB, so secondary tap delay of 1.2 sec is not an issue. Using external by-pass for HEU, the primary side tap delay will be reduced based on by-pass set-point temperature. More detailed data on this topic are not yet available. Tap delay for STU will be for the same conditions reduced because tap delay in BP is disregarded. In addition, HEX in STU is placed in insulated cupboard and thus cools down slower. Regarding a suggested value of waiting time of 10 sec, we suggest to distinguish between individual purposes of DHW tapping. For example, it is less incomfortable to wash hands at 20°C water instead of showering at 20°C .

It can be concluded that HEU needs by-pass if user does not want to face long waiting periods for DHW after period of idling outside heating season. DH companies do not like this solution because of increasing return temperature to DH network, but they should keep in mind that by-pass should be installed anyway at the end of each street and thus individual by-passes for each HEU substation cannot be regarded as a problem. Research how to design by-pass more energy efficiently is ongoing and solutions using by-passed water for floor heating in bathroom is being investigated. STU is from view of DHW comfort a better solution for users (because there is no tap delay on primary side) but on the other hand it needs more space, it has higher initial investment and risk of running out of DHW might happen. Moreover, in some periods STU has worse cooling of DH water. The question which type of SUB is more beneficial for DHN and for users is not clear yet, more data are needed.

Even waiting time for DHW might be seen as quite high. During eight months of running LTDH concept in Lystrup there were no complains. During our measurements we also found out that tested HEU works efficiently, but it might work even better if new components are developed for low-temperature installations.

7. FUTURE WORK

Another Danish governmentally founded project "Full scale demonstration of low temperature district heating in existing buildings" has just become reality. The aim of this new project is to further develop and market mature concepts for future LTDH system, thus creating a solid platform for the future Danish DH technology and industry. Building on two previous R&D projects, the new LTDH concept will for the first time be demonstrated in existing single-family house neighbourhoods. One is Sønderby in Høje Taastrup with 75 houses. The other is with 8 or more houses in Tilst near Aarhus. In parallel, additional optimization and analyses of the LTDH system for low-energy buildings in Lystrup will be performed. Finally, an international guideline will be prepared with input from foreign project partners.

8. CONCLUSIONS

The project demonstrates that LTDH is a realistic way to address the challenges in reducing CO2 emissions in relation to the building sector even building heat demands are decreased significantly. A precondition for this is the accurate design of the overall DH net including special attention when selecting components and designing substations. Measurements together with extrapolated energy calculations reveal DH net loss of 17%, which is on the expected level. This value is one of the most important achievements of the demonstration project, clearly demonstrating Danish low-energy Class 1 buildings can be connected to DH without unacceptable distribution loss. The components for realizing a LTDH system are available commercially today.

Data measurements from site reveal as expected a lower DHW consumption compared to the level stated in the Danish code of practice. The reason for this is the type of apartment where elderly people or young families with typically one child are living. A very distributed tapping occurrence is seen over the day, leading to low coincidence factors for a group of consumers. Also the fact that some apartments have very low consumption contributes to this. In general, the results can be used for this kind of apartment, but it is still risky to generalize results to e.g. one-family apartments. The limited number of apartments for this analysis has to be kept in mind.

Looking at the two SUB concepts applied, STU and HEU, it is not clear which one is overall best fitting into the LTDH system, since both have benefits and draw backs which have to be investigated more in detail. The comfort, expressed in terms of waiting time for DHW after idling in summer period is god, but requires a bypass to obtain sufficient short waiting time for the HEU in the summer period.

In general the Lystrup field results are successful and very promising for the LTDH system, anyhow more detailed investigations have to be done in the future.

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