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New Technology for Cheaper District Heating to Single-Family Dwellings

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Summary

Three new technology concepts intended for servicing single-family dwellings with district heating were developed. The first concept relies on arranging substations in boxes underground and on the borders of each piece of ground belonging to buildings being connected. The second concept represents a development of a previously demonstrated technology based on polymeric pipes arranged inside blocks of open-celled polystyrene. The third new concept is based on vacuum super-insulation of pipes. Both the second and the third technology rely on an innovative network topology according to which pipe branchings are substituted by bending of pipes that run unbroken, from so-called branching stations, up to each building. A patent has been applied for this new topology as well as detailed technological embodiments.

All three technologies were developed with an aim of reducing first costs significantly compared to stat-of-the art technology. In addition, the third concept offers a prospect of concurrently enabling the designer to achieve a dramatic reduction of heat losses, down to around 1/3 of current losses. The first concept is the one that has been developed most in terms of commercialisation. It is intended to demonstrate this concept in field tests in a new Swedish district heating system being built this year.

Introduction

A general trend in the development of district heating all through the years has been to lower first costs. Major contributions in this respect have been made by introducing various types of pre-fabrication, both regarding pipelines and substations.

In most countries district heating has primarily been utilised for supply of heat to bigger buildings. Denmark seems to be the only country where district heating has been applied massively to single-family dwellings. To some extent this can be attributed to dedication towards cheap installation, but also to a heat planning legislation that has generally shielded Danish district heating from market competition.

Historically, Swedish district heating for single-family dwellings has in general followed the mainstream pattern. In the 1970ies there was a slight burst of enthusiasm, but since then low oil prices and other factors has restrained the expansion of district heating, as far as geographical areas of low heat density are concerned.

However, in the last few years there has been a renewed interest, and connections of single-family dwellings have indeed multiplied once again, although today there is a tough competition from heat pumps. In the last three years, the Swedish District Heating Association, with financial contribution from the Swedish State Energy Authority, has performed a dedicated R&D programme towards the development of district heating technology and marketing for single-family dwellings. This paper will summarise results from the single biggest project within this programme.

Project goal

The main direction of our project was set at developing new technology that could lower first costs significantly. At the same time no major concessions were permitted in terms of reliable function and acceptable lifetime. It was acknowledged that heat losses is a major issue regarding district heating for low heat density areas but in the project, in order to focus on first costs, the level of ambition was modestly set at keeping losses at approximately the same level as with state-of-the art technology.

Of course, our strong focus on first costs instead of especially heat losses, is open for discussion. Seen, however, in a current Swedish context of a hard, not to say - for the time being at least - devastating competition from heat pumps, day-by-day penetrating ever more deeply into otherwise ‘district heating ripe’ markets these years, it makes perfect sense. In a broader context, one would probably put equal emphasis on first costs and heat losses.

First costs were defined as costs for all equipment from a point of delivery from an existing, big district heating network to heat delivery in-house, excluding any costs for conversion of building internals and value added tax. Thus, speaking in terms of current technology, first costs would comprise all costs needed for establishing a local distribution network and substations, including metering equipment, but not any possible cost of installing a hydronic central heating system to replace direct electric heating,

As is generally known, first costs will vary significantly with local ground conditions and other physical circumstances. The cost goal was not expressed precisely in this respect. It was only agreed that technologies developed should be applicable almost everywhere. This turned out to have important consequences: Initially in the project quite an amount of effort was spent on considering horizontal drilling techniques. But we ended up judging that, although this technology is indeed a very interesting option, currently attracting significant development, not only within district heating, it will presumably for many years ahead mainly be confined to special locations (for instance crossing of a river) or to geological conditions where a major fraction of stones within the soil can be excluded.

The first-cost goal set out should be interpreted as applying to ‘medium’ conditions in all respects, including local market share, stipulating a minimum of 70% after some years from start of network installation. Another project within the major programme established (ref. Sandberg) that for a range of existing district heating networks, first costs varied between 7 000 and 13 000 Euro per dwelling.

Our goal was set at a **maximum of 5 000 Euro per dwelling**. Although, as will be appreciated, this goal is quite ambitious, we believe that we have developed technologies that stand a good chance of meeting such an expectation. Since, as will be presented here below, we decided to put forward several alternative technologies, one of them quite revolutionary, and none of them have been tested in field yet, no proof for this can be given at present. However, we shall try to argue persuasively for the plausibility of our estimation.

For the one mentioned technology that deviates least from current technology, we in fact believe that our estimate can be claimed to be a qualified one. Several of the people that were engaged in our work group have spent decades in designing and running district heating systems under quite differing conditions. On this basis, they were able to make good estimations regarding major cost components, in a breakdown of estimated total costs for pipes, ground digging, etc.

A major emphasis on reducing installation time

The first question we asked ourselves at project set-out was this: Could some general observations provide good starting points for dedicated work against the defined goal be set out?

As is generally known, in the small diameter range on-site work costs tend to make up a significant fraction of total first costs. Moreover, if one defines material costs narrowly as costs for raw materials only, these costs will make up only a small percentage of total investment costs. Another observation - not specific to district heating – is that in industrialised countries each working man-hour spent in field is around twice the cost for a working man-hour spent in a factory.

From these observations we concluded that the following four priorities could be established:

1. A more speedy installation in all respects
2. A continuation of the historic trend towards ever more pre-fabrication,
3. Intensified standardisation and reduction of number of products,
4. Bigger product markets to lower unit costs.

Since the first of these priorities seemed to be the one most easily tractable in a short-time perspective, we decided to concentrate initial efforts on this goal, keeping the others in our minds.

Our colleague within the working group, Mr. Lennart Bramsved of PEAB, a major Swedish construction company, drew our attention to the reflection that currently a major factor tending to slow down field work is that specialised craftsman expertise is needed whenever reliable pipe branchings are made. This is required to secure tight and robust pipes imbedded under-ground, both in terms of inner, pressurised pipe and shield pipe carrying heat-insulating material. Indeed, since branchings are well-known to be the potentially weakest point of a state-of-the art system, qualified and careful work is certainly called for here.

Based on this, we deducted that if one could define technologies that would eliminate the need for in-ground embedded branchings, without sacrificing the overall degree of system pre-fabrication, but rather the opposite, there would be a good chance of fulfilling the first of the priorities listed here above.

Creative work based on this work thesis resulted in what can appropriately be divided into three new technology concepts. The second and the third of these concepts share a common, new connection / network topology principle (which will be explained here below), but are quite different regarding particular pipeline elements. The first new technology concept is the one that differs least from state-of-the art technology, which of course is an asset in terms of how quickly it can be made commercial and regarding the degree of certainty with which one can project probable first costs and running costs.

The last new technology concept relies on vacuum super-insulation and probably is, if it proves valid, the one that holds greatest promises for the future. The other side of the coin is that it is far from commercially mature at this stage and thus carries much more uncertainty. It does, however, offer a prospect of combining lowering first cost concurrently with a major reduction of heat losses.

First new technology concept

The first type of new technology we propose relies on the main idea that instead of installing a substation inside the building (or immediately outside the building adjacent to a wall, as is sometimes done, with varying degree of acceptance in terms of architectural appearance), the substation is arranged inside a box installed mainly underground and immediately adjacent to the border of the premise of the house to be served, typically adjacent to a pavement.

A main point in this concept is exactly that it dispenses in-ground imbedded branchings, as just set out here above.

Another important feature is that an overall network topology of ‘comb’ connections can be employed. That is, one can replicate an arrangement sometimes used to have main pipes running from one building to another with no by-pass of main pipes. In our system, main pipes will run from one box to another. Although such a ‘comb’ arrangement is favoured by some district heating engineers, due to savings in pipeline work, it sometimes runs into difficulties when it becomes necessary to arrange pipes to be drawn across a property owned by a person who is not a district heating customer. However, when our system configuration is employed, with substations in boxes arranged on the border of the premises, there is no such difficulty: A non-district-heating customer can simply be by-passed by pipes running adjacent to his property, typically along or within the pavement.

This first new concept is going to be demonstrated in a commercial, new district heating system that will be owned by the municipal energy company of Trelleborg, a community on the south coast of Sweden. Here, a group of existing single dwellings will be connected as part of a major district heating scheme also to include connection of larger buildings.

For use in this application, an existing pre-fabricated type of substation was modified in a co-operation with the manufacturer, Danish Danfoss A/S. After some adjustments, a prototype performed well in a laboratory test. An appealing aspect of our new concept is that substations can more easily be taken out for service or replacement than when substations are positioned in-house. A prototype box, with fixtures and pipeline interface, was built to demonstrate this facility. The substation is of quite light weight and could easily be lifted out.

As can be seen from fig. 1 there will be four (blue) pipes projecting from each box to serve each building, two for heating supply and return, and two for hot service water, viz. a supply and a circulation line. A smart feature built into the concept is that in cases of big service water demand, both hot water lines function as supply lines (so-called ‘reversed’ circulation), due to a special connection arrangement. This will help reduce pipe dimensions and hence heat losses.

Admittedly, the new concept draws an additional cost for the box and its installation. For the demonstration plant it was decided to rely on boxes made out of concrete, at a cost of around 400 Euro. Probably, in series or mass production this cost can be reduced significantly. - For many other applications, plastic boxes are being

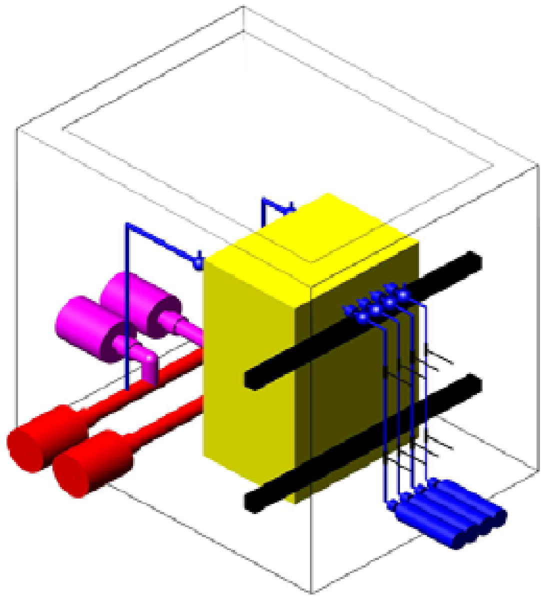

Figure 1 An external substation box with district heating connecting pipes (to the left) and four house connecting pipes (to the right)

manufactured in great numbers at low cost, and probably some manufacturer could be found who could include our box within a production line already prepared for other applications.

There are of course further pros and cons with the new concept: Some district heating people, to whom we presented our concept, expressed concern that the box, which is not supposed to be arranged completely contained underground, in order to facilitate inspection, may collide with plantations or the like. On closer examination, however, this aspect may be turned into more of an asset than a liability, in that boxes of smart designs could be combined with special plants, mailboxes etc. In the first version, control equipment of the substation will require low-voltage electricity supply; later versions may not. In fact, high-voltage electricity supply could even be convenient, since one might fit the box with a plug to which an electrical lawn mover or electrical lines of garden lights could be connected.

Another issue is cold water supply. When a box is arranged not too far from a towns water line, a connection from this line to the box could be drawn. In other cases it will be necessary to have a line of cold water supply drawn from the building to the box.

Second new technology concept

Our next main step was to see if we could go further along the line of eliminating underground, embedded branchings. This led to a new type of network topology implying a concentration of branchings to so-called branching stations, common to a group of, say 10 buildings. With such stations one would replace branchings of pipes by bending transitions of un-broken conduits. For this a patent has been applied, which in a Search Report has been evaluated positively regarding novelty and inventiveness (ref. Frederiksen et.al.).

As can be seen from fig. 2, this topology will require that a whole bundle of conduits (CON) run in parallel, extending from a branching station (STA), which could be arranged on ground or underground. At first such a whole bundle may seem quite forbidding. However, both the second and the third new technology concepts offer ways of handling this obstacle, as will be explained here below. In addition to single-family dwellings (BUILD) there could be a single, bigger building (BUILDBIG). Each station could employ on or more heat exchangers (HE), providing hydraulic separation of fluids in the local network (DISTR) and in conduits (CON*) of a heat supply network.

Apart from eliminating imbedded branchings, the new type of network topology offers the prospect of partly or completely eliminating substations in buildings, replacing them by a much smaller number of bigger substations within the branching stations. This could help reduce specific first costs for substations. There are indeed existing network solutions offering the same feature. But, since such concentration of substations requires that hot service water will be generated in the substations, there will be 4 lines instead of 2 in the network.
- With state-of-the art pipeline configurations this requires a lot of branchings.

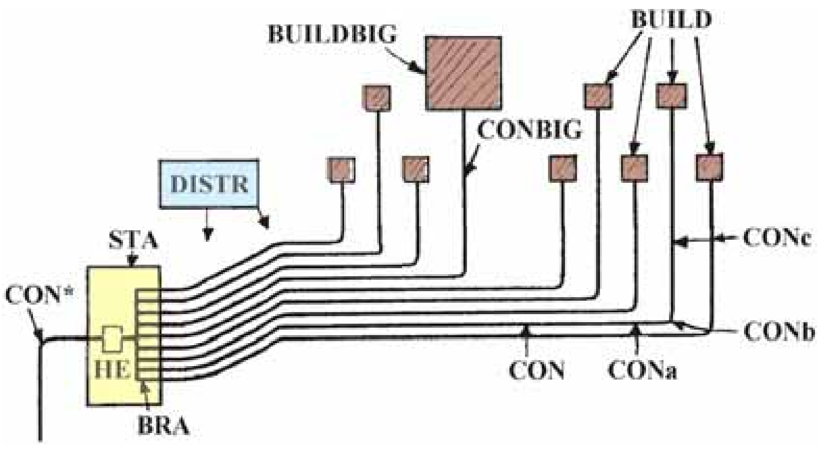

Figure 2 Network topology implying a concentrating of branchings to so-called branching stations, common to a group of buildings.

This second new technology concept further proposes that the special type of topology adopted be combined with a fairly recently introduced new type of pipeline technology. Although un-conventional so far, this technology has been tested successfully, both in laboratory and field tests (ref. Sällberg et.al.). In its basic conception it relies on polymeric PEX medium carrying pipes (of course provided with diffusion- blocking built-in membranes) fitted inside open-celled light-weight Expanded Polystyrene (EPS) blocks. This latter material is offered by many suppliers at low cost for numerous applications, including protective package of electronic equipment and insulation in various types of building constructions. In many of these applications significant load-carrying capacity is required.

Due to the EPS material being open-celled, it is prone to be soaked by water if not being properly protected. However, if one avoids installations below ground water table, establishes good drainage adjacent to the system, and provides a shield that will protect the material from being exposed to direct percolation from water seeping down from above, the amount of moisture within the EPS blocks can be kept within an acceptable level. To be sure, the heat transfer coefficient will be higher than with state-of-the art polyurethane foam (roughly the double value), but thanks to a rectangular configuration and the fact that ditches need be only slightly wider than the blocks, more insulation material can be fitted into the ground, under conditions that can be claimed to be comparable to those of state-of-the art round pipes. Due to these geometrical features, there need not be any increase of heat losses with the EPS-PEX technology.

Furthermore, the EPS-PEX system in our tapping can be arranged such that bundles of un-insulated PEX pipes emanate from a branching station to share a common insulation within EPS blocks. Thereby, the total size of the bundle can be kept within rather narrow extensions. Thus for instance, with 4 layers of 10 pipes, each being of outer diameter 25 mm, 4 pipes for each building, the sidewise extension could be no more than 2 x 0.15 + 10 x 0.025 = 0.55 m, allowing for 150 mm insulation on both sides. Such a width is quite compatible with common sizes of pavements.

Fig. 3 shows a cross-sectional view of such a configuration, together with a roll (with BEARings) arrangement by which all pipes belonging to a certain (of the 4) layers are rolled out simultaneously. As can be seen, two layers representing hot service water and circulation water have been arranged directly on top of each other, primarily to save space in the vertical direction, which is permissible since these two lines will not differ substantially regarding water temperature. The roll arrangement comprises a roll (arriving on a truck) mounted on a rack with wheels, to be rolled along the main ditch having been dug out previously.

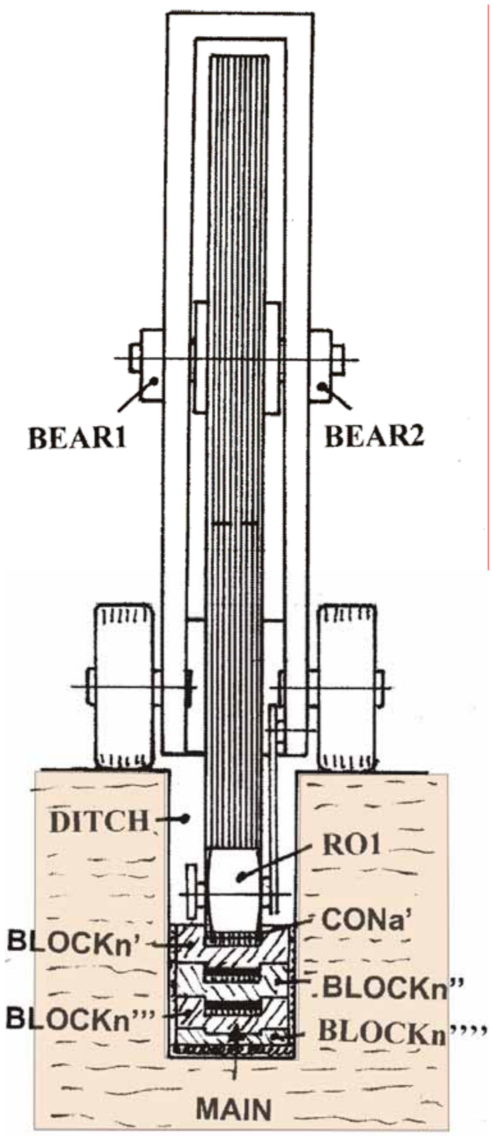

Figure 3 A cross-sectional view of roll arrangement by which all pipes belonging to a certain (of the 4) layers of pipe bundle are rolled out simultaneously.

It is envisaged and has been demonstrated, by design drawings at least that it should be possible to avoid any cutting of pipes on site. Thus, in the factory each pipe will be cut to its appropriate length and mounted at a specific site on the roll. The roll can be designed in such a way that when it has been brought to each of positions along the main line, where a bending off of pipes up to a certain dwelling is supposed to take place, this can be done rather easily. It some cases it will involve an operation by which a small roll part is de-coupled from the big roll, such that the remainder of the pipe up to the house can be rolled out from this small roll part. In case of buildings not far away from the main line, it may not even be necessary to de-couple any roll part, the pipe can simply be taken out manually. In any case, one operator will carry the big roll slowly ahead, while others take care of bent-off pipes, arranging them to lead up to each one of the buildings to be connected. Since there are four layers of pipes, in total four (or maybe only three) big rolls are called for.

A number of further design details of this concept have been worked out in theory. Although there are more items to be settled prior to field tests, we judge that this concept stands a good chance of reducing installation time for the otherwise time-consuming underground pipe-work by as much as 50%. For instance, it seems reasonable to project that an installation serving 10 dwellings by a team of 5 men could be done in one week instead of two weeks, which is what would normally be required. Apart from savings in man-hours there will be the additional benefit of reducing the time when constructional work will cause a nuisance to the public, in particular those who inhabit the area. Admittedly, installation of underground branching stations will call for some resources, but this work is generally less demanding in terms of logistics and requires less space that do pipelines. Also, work associated with the branching stations will be less disturbing to the public.

Third new technology concept

This concept relies on super-insulation, i.e. insulation with a coefficient of heat conduction significantly below the one has to rely on today, say 0.0025 W/mK instead of 0.025 W/mK. This can only be effectuated by establishing and keeping the insulation under a vacuum. It is envisaged that such a low heat conductivity can be taken advantage of, both to shrink pipeline dimensions and to reduce heat losses. Thereby, another solution is offered to the previously described, immediate obstacle of having a whole bundle of pipes emanating from a branching station: Whereas in the second concept (described here above) total dimensions were kept moderate by separating the medium carrying pipe from its insulation, with the third concept the entire pipes are instead made of smaller dimension.

Vacuum super-insulation has been known for many years and has gradually been introduced into various applications. From everyday experience we are all acquainted with the hot-drink container that is insulated by a vacuum maintained between glass walls. Another example is provided by super-insulating foams that have improved insulation of refrigerators.

Extremely efficient super-insulation can be attained by using a succession of heat-reflecting foils kept at distances from each other. Thereby, a reduction of heat transfer by a factor even exceeding 100 can be attained. However, in district heating pipes is seems more appropriate to target a factor of around 10, which will offer a selection of alternative substances that by themselves will more or less provide mechanical integrity.

Throughout the years, various attempts have been made to employ super-insulation to district heating (for instance ref. Zinko et.al.), but until recently only concepts with stiff conduits were offered, not flexible conduits, which is what we propose. Flexible pipes of this type could open up for, not only the common advantages with flexible district heating pipes, today common in small inner pipe dimensions, but several additional facilities. Thus, one would able be to employ the kind of added pre-fabrication to final lengths and rolling up pipes described already for our second new concept. By using a PERT, a recently introduced, more flexible and weldable high-temperature polymeric material, instead of PEX (which is not weldable), combined with heating of pipe rolls, a contribution towards highly flexible conduits can be made.

The fact that we in this concept are dispensing with in-soil branchings altogether will greatly reduce the risk of leakage of air into the insulation, so that there will be a reduced risk of vacuum being destroyed. Additionally, the common branching chamber, employed within our new type of network topology, offers a possibility to suck out moderate amounts of in-leaked air and to monitor vacuum, with equipment that will be shared by all dwellings connected to the specific branching station.

An ambitious comprehensive goal for such super-insulated pipes applied to single family dwellings could be expressed as follows:

- Reduced dimensions by a factor 2-3, so that smallest conduits will have a diameter of, say 40 mm.
- Cables that are as flexible as an optical cable, offering use of new techniques of cable laying.
- Standardised pipe dimensions, for instance 20 mm inner pipe diameter in most cases.
- Reduced heat losses by a factor 2-3, such that typical losses of 15% could be reduced down to 5%.

We realise that this prospect which can appear as a *fata morgana* will of course not be attained overnight. We are, however, keeping a dialogue with others who along with us try to develop super-insulated district heating pipes (ref. Beschorner, M. & Müller C., Fränkische Rohrleitungen GmbH). A concerted effort, with contributions from several developers, could bring about complete solutions that would be very attractive to district heating engineers as well as companies running district heating schemes, especially in low heat-density supply areas.

Patent rights

A patent (Frederiksen et.al.) has been applied for the new kind of network topology, covering both the second and the third new technology concept. Further patent rights, not covered by the first patent application, are underway.

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