Ranagård with new 4GDH technology

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Abstract

From now on, in 2021, new buildings in Sweden must fulfil the nZEB, near Zero Energy Buildings, concept. It implies low mean U-value (U_m) of 0.30–0.40 [W/m² K] in the buildings' envelopes for obtaining low heat demands according to the Swedish National Board of Housing, Building and Planning. Furthermore, the new buildings must have sufficient mechanical ventilation with heat recovery. In addition, the buildings could preferably even be self-sufficient of electricity. In this context, and with a new renovation wave carried through in Europe, a new technique with low-temperature district heating is a smart, even a wise, solution. The technique is based on renewable, recovered, and stored heat.

Halmstad Energi & Miljö, HEM, and the Halmstad University and Malmö University are carrying out a transdisciplinary project in cooperation. In Part 1 of the project HEM is installing district heating for 550 new dwellings in the Ranagård district. The area will have several real estate companies/owners. HEM has planned for a sharp system solution, which use considerably lower temperature than conventional district heating. Halmstad University has developed this network configuration, which so far, never has been tested in full scale. The new technique benefits with lower heat supply costs for using renewable, recovered, and stored heat in future district heating. The Universities are making two research analyses in addition to this extension. Part 2 of the project aims to survey acceptance, for identifying any hindrance occurring when new technology is introduced. Analyses of interviews within the construction and energy industry will show their decision making in relation to new technical solutions. Part 3 pertains to quality assurance of the new district heating technology, to ensure that this new technology is fully implemented. This paper is a first report on the implementation.

Introduction

According to the Heat Roadmap Europe: *Towards a decarbonised heating and cooling sector in Europe* (Mathiesen et al 2019) there is enough excess heat for heating all housing and premises throughout Europe. The statement from the study is based on the Pan-European Thermal Atlas (Heat Road Map Europe 2021). Furthermore, district heating should be increased from today's level of 12 % up to approximately 50 % in 2050 – ranging from 20–70 % depending on the country to encounter the climate change.

In the US the first generations of district heating, 1GDH, were established in the 1880s and based on supplying steam distributed in concrete pipes. This technique is still in use in New York and Paris. The second generation of district heating, 2GDH, were used in Germany starting in the 1920s and based on supplying hot water over 100 °C instead of steam. It was known as the best technique during the period between 1930–1970.The third generation of district heating, 3GDH, was invented by engineers. It still had a high supply temperature of 80–95 °C, but prefabricated and pre-insulated pipes for supply and return of the hot water. Altogether, more efficient. It was considered as the best available technique, BAT, from the 1980s and on. Today the fourth generation of district heating,

4GDH, was tested in Denmark in the 1990s for distributing solar heat. Its main characteristic is significantly lower supply temperatures below 70 °C resulting in lowered heat losses and the possibility to use excess heat and to use plastic pipes (Lund et al 2014 and 2018). Low-temperature district heating using traditional two – supply and return – pipes in one casing in the distribution grid, has been tested in Germany, Sweden and Denmark. 4GDH is now often considered to be the best available technique. The different types of heat generation is showed in Figure 1. One alternative 4GDH is using three pipes where the third is for supplying water circulation without any temperature contamination of the true return temperature (Averfalk & Werner 2017).

In Halmstad the newest 4GDH, fourth generation district heating, with three pipes instead of two will be implemented for the first time. It will supply new nZEB buildings, according to the Swedish concept, in Ranagård, Halmstad.

The aim and objective of the study is to explore and find answers to the following questions.

- What opportunities and what holdbacks lies in the development of novel techniques and especially the 4GDH, fourth generation district heating, with low temperature systems and three pipes?
- Are developers ready for novel systems?
- What impacting decisions are taken in construction and energy industry and which ones are needed?

The methods in use for this study are mainly literature survey, and making interviews with actors in the fields of construction, in housing and real estate, and in the energy field for use when making analysis of the project and processes.

Background

The Swedish parliament has set a goal on having no net GHG, greenhouse gas, emission latest in 2045 and thereafter achieve negative GHG emissions (Skr 2017/18:238). A new Climate Act (SFS 2017:720) came into force January 1st, 2018 and a Climate Council has been initiated.

Emissions from housing/real estate and premises for service, agriculture and other commercial aims have decreased 87 % between 1990 and 2016, from 9.5 million tons of CO_2 equivalents to 1.2 million tons. Mainly due to replacement of individual oil-based heating and hot tap water in housing and premises by district heating, heat pumps and biofuels (Skr 2017/18:238).

According to the National Energy Agency (Energiläget 2020) district heating is the most common system for generating heat in the Swedish building stock. About 58 % of the heating and hot tap water in housing and premises are generated by district heating. The district heating is usually generated by combus-

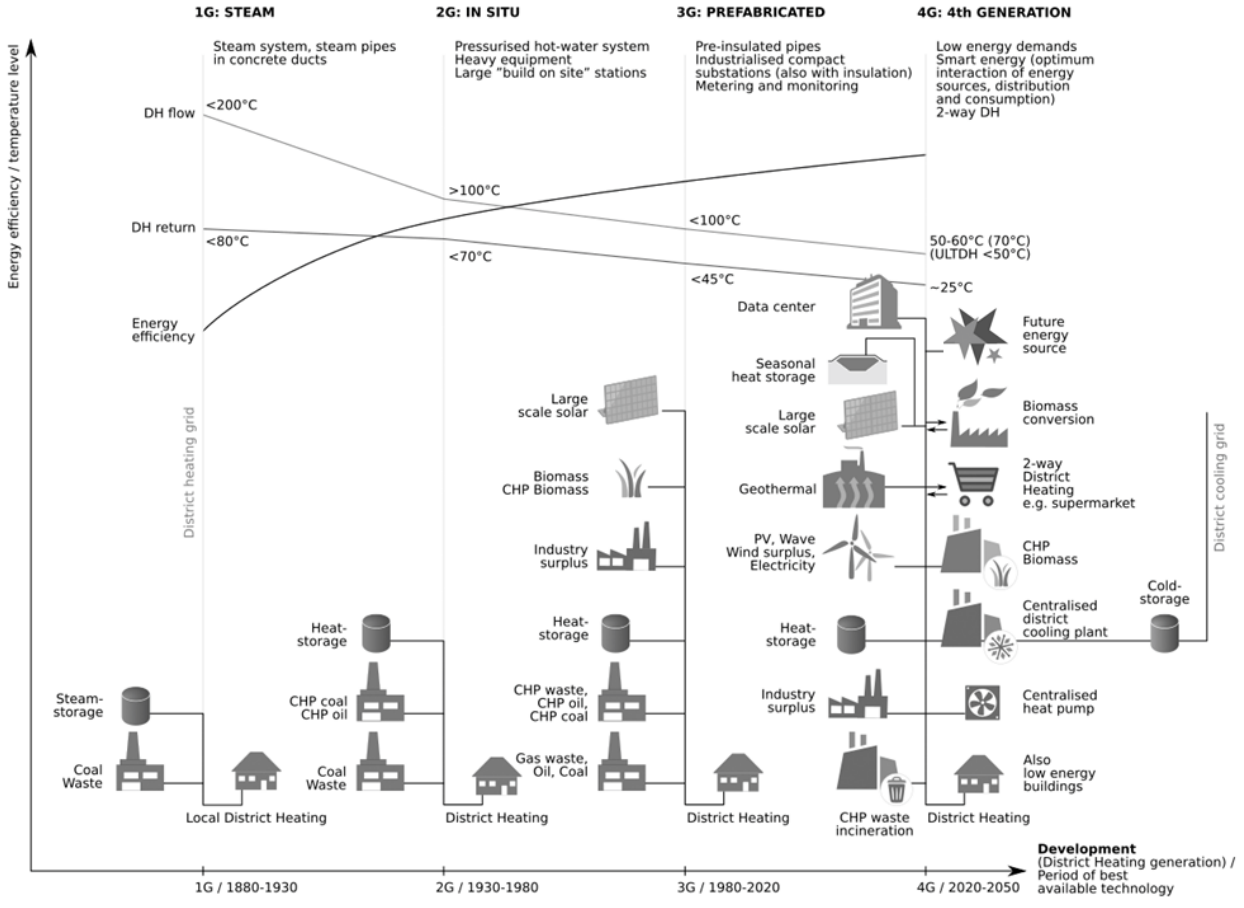


Figure 1. The concept of 4GDH and previous generations. Illustration from Lund H. et al 2014 and 2018.

Table 1. Maximum primary energy, installed electric power for heating, average heat transfer coefficient, and average air leakage for detached houses, multifamily buildings and premises. 1 kWh=3.6 MJ.

	Energy performance expressed as primary energy (EPpet) [kWh/m² Atemp and year]	Installed electric power for heating (kW)	Average heat transfer coefficient (Um) [W/m² K]	The envelopes average air leakage at 50 Pa pressure difference (l/s m²)
Dwellings				
Dwellings > 130 m² Atemp	90	4.5 + 1.7 x (Fgeo – 1)	0.3	According to section 9:261)
Detached houses >90–130 m² Atemp	95			
Detached houses >50–90 m² Atemp	100			
Detached houses ≤50 m² Atemp	No demand	No demand	0.33	0.6
Multifamily buildings	75	4.5 + 1.7 x (Fgeo – 1)	0.4	According to section 9:261)
Premises				
Premises	70	4.5 + 1.7 x (Fgeo – 1)	0.5	According to section 9:261)
Premises ≤50 m² Atemp	No demand	No demand	0.33	0.6

Section 9:26 in BBR regulates the envelopes air tightness. The building's envelope should be tight enough to meet the demand on the building´s primary energy and installed electric power for heating.

tion of biofuel, like waste and residues from foresting and from wood industry, 62 %, excess heat 8 % and heat pumps 8 %. The rest is a mix of electricity, peat and natural gas among other fuels.

Attempts to replace fossil raw material with wooden raw material within the manufacturing industry though, has created a situation of competition about the use of wooden material. Simultaneously, new demands on near Zero-Energy Buildings, nZEBs, are implemented in the building regulations-mandatory provisions and general recommendations, BBR (BFS 2011:6 to 2020:4), for new buildings, and within the EU a renovation wave is initiated to reduce the energy consumption, with connected CO_2 emissions, within the existing building stock.

THE NZEB CONCEPT

All member states within the EU must transpose new EU rules on the use of energy in buildings into national law i.e. to implement Directive EU 2018/844 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

> Each Member State shall establish a long-term renovation strategy to support the renovation of the national stock of residential and non-residential buildings, both public and private, into a highly energy efficient and decarbonised building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero-energy buildings. (Directive EU 2018/844, page 7.)

In Sweden the nZEB concept came into force September 1st, 2020, and has its own interpretation, applicable for new buildings as well as for renovations and extensions. BBR (BFS 2011:6 to 2020:4) provides minimum requirements and there are developers that are choosing to build better and more energy efficient than the minimum level.

In short, the concept implies a certain demand of efficiency with a maximum primary energy, but there are geographic adjustment factors specific for each municipality, adjusted to the local climate. It is stretching from 1.9 in the Northern parts to 0.8 in the South part of Sweden. The geographic factor only applies for the heating part of the total energy use. There are also weighting factors depending on choice of energy, see Table 2. Both Table 1 and 2 are translated from BBR (BFS 2011:6 to 2020:4).

In addition to calculation of the primary energy one must fulfil the average heat transfer coefficient, but it can be higher if there is e.g. PV panels generating electricity that is provided for the building's heating or hot tap water. The own energy from sun, wind, ground, air or water must though be generated on the plot.

The heat demand is also depending on the degree of ventilation, which in turn depends on the building space in m². Adding to the primary energy and installed electric power for heating is possible when a building is larger than 130 m², and there are higher demands for ventilation. There is also a limit for SFP, specific fan power, ranging from 0.5 when only using mechanical exhaust air and up to 1.6 when using supply and exhaust air with heat recovery and cooling.

Those who builds today must, to a larger extent than earlier, consider how the building as a system is interacting and how the users make use of it. With all the various factors to take into account in the calculations, and influencing the primary energy it is almost impossible to make a comparison between different buildings based solely on the figure for primary energy. It gives insufficient information on the technical quality. If two buildings of the same type choses a separate oil boiler respectively choses district heating, the one with an oil boiler will have to be better built/have more insulation added than the one connected to the district heating because of the two different weighting factors (Elmroth 2020).

Table 2. Weighting factors based on choice of energy.

Energy carrier	Weighting factor
Electricity	1.8
District heating	0.7
District cooling	0.6
Solid, liquid, and gaseous biofuels	0.6
Fossil oil	1.8
Fossil gas	1.8

Table 3. Heat transfer coefficient to aim for in separate parts of a building U_i translated from BBR (BFS 2011:6 to 2020:4).

U_i	[W/m²K]
U_i roof	0.13
U_i wall	0.18
U_i floor	0.15
U_i window	1.2
U_i entrance door	1.2

The same demands for primary energy applies when extending or alter an existing building, but if this is not possible then the demand for low heat transfer coefficients in the separate parts of the envelope should be fulfilled, see Table 3. This applies e.g. if the existing building has historic and/or cultural values.

4GDH WITH THREE PIPES

The implementation of nZEB for new and existing buildings will, nevertheless, decrease their need for heating and it will continue to do so. A lower need for heating could therefore be met by a low temperature heat supply such as heat pumps or low-temperature district heating. Heat pumps are running on electricity which today is regarded as a scarce resource as more functions in society including transport requires electricity for running. In this regard the low-temperature fourth generation district heating, 4GDH, seems more suitable from both an energy view and society's view. The total number of buildings that can be supplied by district heating increases as heat generated can be distributed with lower temperatures to more buildings by existing plants and grids. Lower temperatures also imply that more excess heat from industries, solar energy, from server halls and other heat generating activities can be supplied at lower costs and thus lower the use of biofuel. There is a plethora of possible supply combinations to use in district heating, and when formulating the solutions, one could always consider and make use of the various local conditions.

In short, the 4GDH with three pipes was first presented in a conference paper 2016 by Averfalk and Werner and later in an article 2018 by the same researchers. It differs from the third generation district heating, 3GDH, with two pipes in three technical ways. Firstly, the third pipe, secondly heat exchanger units in each flat in multi-family buildings, and thirdly longer thermal lengths in heat exchangers. In addition, ICT supervision can be used with the heat exchangers and thus avoiding todays common temperature errors (Averfalk &Werner 2017).

Basically, one has to navigate within the frame for existing technique to achieve the advantage that the 4GDH system solutions have. The new network configuration gives a lower temperature in total. Traditionally Swedish supply temperature is 85 °C in 3GDH grids and 46 °C in the return pipe while the new 4GDH network configuration has a supply temperature of 50–55 °C and 20–25 °C in the return pipe.

Traditionally, in two pipe systems, for supply flow and return flow, a recirculation flow is necessary for supply of domestic hot water when the heating demands are low in the summer. In detached houses, the recirculation flow is managed by a bypass valve and in multi-family buildings by maintaining the hot water circulation systems. The latter is what the third pipe in the 4GDH does in the distribution system as shown in Figure 2.

A novel 4GDH system with three pipes operates with one supply and one return pipe, and a third circulation pipe which will lower the temperature in the return pipe. This is contrary to e.g. a German system in Berlin which has two supply pipes and one return pipe (Frederiksen & Werner 2013). This implies separate distribution for heating and domestic hot water. It is one way of reducing heat losses in the grid and in total. In early proposals for grids, three pipes were utilised in the service between the main pipes and substations using two pipes for supply and one for the return (Böhm & Kristjansson 2005; Li et. al. 2010). The gain was suggested to be less heat loss while only one pipe was in use in the summer at low demands which in turn would imply a heat storage.

In Sweden the circulation pipes for hot tap water in buildings connected to 3GDH with two pipes may not undercut 50 °C in any part of the installation (BFS 2011:6 to 2020:4). The separate substations/units for heat exchange in each flat in the 4GDH with three pipes will eliminate the secondary hot water circulation with its high return temperature. In addition, the units will enable separate metering for each flat and allow the individual end user to determine the indoor temperature.

Longer thermal lengths in the substations, as part of the 4GDH system with three pipes, are better adjusted to new nZEB buildings with low heating demands than the 3GDH with two pipes currently in use in Sweden.

The actual temperature in the 4GDH supply pipe is low, 55 °C, but high enough to ensure that no growth of Legionella will occur. The national board of housing, building, and planning has set the limit higher than 50 °C but lower than 60 °C for hot water at the tap to avoid scalding (BFS 2011:6 to 2020:4).

Interviews on new technique and 4GDH with three pipes

So far only slightly more than ten interviews with energy companies and housing companies have been performed, but some answers are the same regardless of respondent. Firstly, they have a long-term perspective working with systems and buildings that will last for periods of 80 to 100 years implying that any decision will have long-term consequences. Hence a cautious and quite inert process when studying alternatives in investments.

Simultaneously the larger energy companies have separate sections for innovation and business models. An early cautious conclusion might be that the larger the companies the more likely they are to test new solutions while the smaller companies are tied to limited economic frames that do not allow any tests implying risk taking.

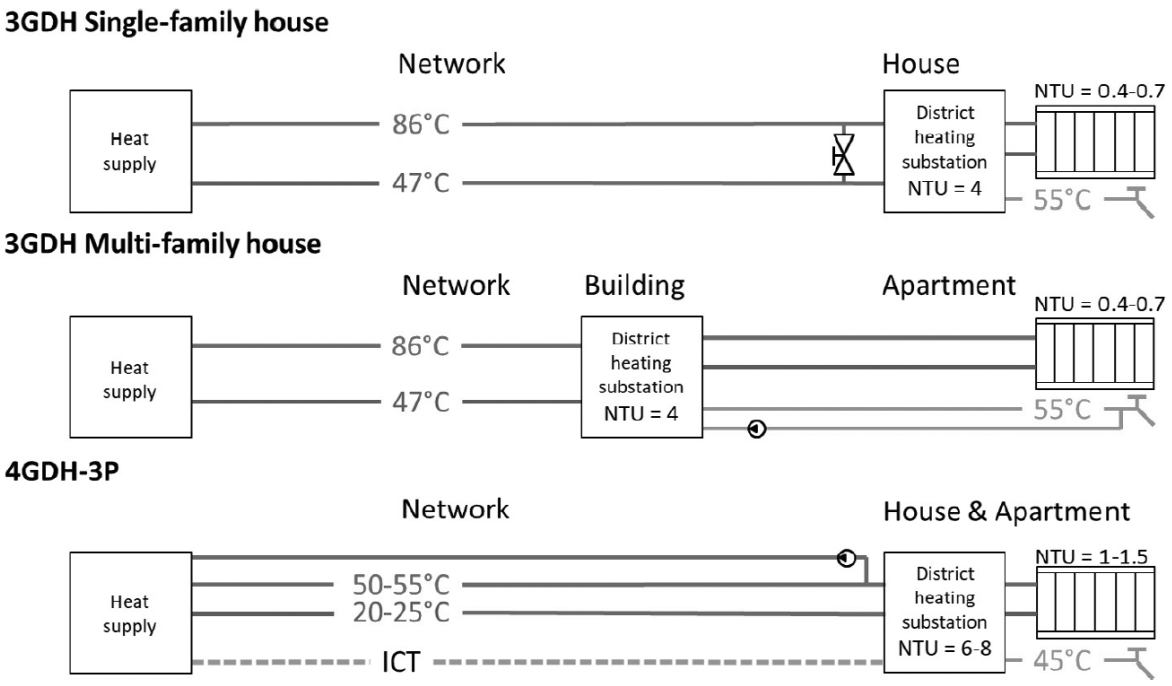


Figure 2. Sketch of two 3GDH systems currently in use and of the novel 4GDH which will be tested in Ranagård. The 86 °C lines in the 3GDH denote the supply and the 47 °C lines the return. The 55 °C lines in the 3GDH denote domestic hot water. NTU denotes the number of heat transfer units and thermal lengths in substations and radiators. In the 4GDH the 50–55 °C line denote the supply and the 20–25 °C the return. Here the 4GDH, the domestic hot water has 45 °C. ICT information and communication technology, the dotted line, is used in the 4GDH system for continuous measuring and control enabling improvements in locating temperature errors (Gadd & Werner 2013). Illustration by Averfalk & Werner (2018).

Table 4. Heat demand in Ranagård with input from AFRY engineering.

Heat demand	Heating, MWh	Hot tap water, MWh	Total, MWh	Specific heat demand, kWh/m²
Area 1	1,417	547	1,964	76.4
Area 2	1,333	542	1,875	77.5
Area 3	521	194	715	75.6

All respondents in interviews so far are convinced that we will still have more district heating in the future, and that 4GDH with three pipes could be one of the good solutions. They also seem to be convinced that it will be based on a variety of energy sources like excess heat, solar heating, and some sources of which we do not know yet. This implies use of low tempered heat generation which will suffice for heating new energy efficient buildings. Water can always be heated in various ways and thus we can never be locked into one energy source for heating when using the district heating grid.

New ICT technology for metering energy is implemented in all the companies for quick location of errors and leakage and of course from the energy companies view for debiting the end users' electricity use. In housing companies, the heating and hot tap water is included in the rent. All companies have policies and/or action plans for sustainability and for achieving a fossil free future according to the national objectives.

Some of the bigger energy companies have tested 4GDH with low temperature in their district heating systems, but not with three pipes. They show an interest in the subject matter though, and are waiting for the first technical report on the implementation in the Ranagård project.

Ranagård

Ranagård was initiated by the board of HEM. The board consist mainly of local politicians and co-opted employee representatives. As a municipal company HEM has a policy including objectives on sustainability and about using novel technique. A pilot study was made showing reasonable investment costs and return. The combination of 4GDH and built environment according to nZEB demands is a possible, theoretically logic and well-balanced solution for a sustainable society, which will be shown in Ranagård.

The district Ranagård is situated in the West parts of Halmstad. There will be built 550 dwellings, of which about 80 will be detached houses, with various forms of lease and ownership by fourteen developers and housing companies. The district is divided into three development areas. Table 4 shows the calculated heat demand in the nZEB buildings for the whole district.

The construction of housing will start with the first area in 2021. At a visit at the site in May 2021 the 4GDH with three pipes, the water supply and other utilities, and roads were on-going in Area 1. All infrastructure in Area 1 including the culverts for 4GDH with three pipes supplying the 1,964 MWh heating demand was built by HEM, Halmstad Energi & Miljö, and finished in 2020. Area 1 has the fourth generation low-temperature district heating, 4GDH with the three pipe solution.

THE PROCESS

The first task for HEM was to design the unit for shunting the high temperature water from district heating to the low temperature district heating grid in Area 1. Thereafter the actual three-pipe system was to be designed. It took time, and discussions with several consultants about different solutions were needed for the three-pipe solution which required an innovative thinking. As a precaution HEM decided to use steel piping if higher temperatures should be needed in an emergency, instead of the plastic PEX-piping. Steel piping implies welding and to weld three pipes lying close when joining the lengths caused practical problems. The innovative solution was to have a third single pipe in a second casing. The heat exchangers for the flats were a bit more difficult to get. The units on the market did not meet the functional requirements. A special solution implicating a reconstruction which was an option. There were even discussions on the accessibility to the service building.

Suppliers had to be found. The Public Procurement Act (SFS 2016-12-01 to 2019:970) requires accurate tender documents



Figure 3. Ranagård Area 1 in May 2021 with the service building were the district heating is entering the area.



Figure 4. Ranagård Area 1 showing the buildings and the 4GDH with three pipes district heating grid.

and making them is time consuming. In this particular project, it was also about a special solution. The tender documents were sent to several relevant suppliers. An existing heat exchanging unit from a nearby company could be altered for the specific purpose. The shunting unit and the single third pipe could be delivered by any company.

The concept with three-pipes should preferably be combined with separate substations in every flat for optimal efficiency (Averfalk & Werner 2018). It would in addition enable separate metering and debiting of heating and domestic hot water use. Hence, the process included discussions with housing companies about substations for heat exchange in each flat. Separate substations implies that shaft-space within the building would have to be enlarged if used also for extra piping diminishing the rentable space. A separate shaft was discussed, but who would own the shaft, who would own the pipes and who would get the insurance? All these parts delayed the process and project more than six months.

Separate metering and debiting of heating and domestic hot water is not common in a multifamily building with tenants in Sweden. Traditionally the cost for heating and domestic hot water are included in the rent and the tenants share the cost equally. Separate substations in a multifamily building would also imply a larger investment for the developer or extra costs for the tenants than one traditional bigger heat exchanger supplying the whole building. Furthermore, in the discussions it did not seem fair to let the tenants answer for the cost of separate substations. Owners of detached and semi-detached houses on the other hand do normally have separate heat exchangers, metering, and debiting. In these instances, an optimal efficiency could be achieved in Area 1 where the 4GDH is implemented.

HEM had expected higher costs for testing the new innovative technique and the additional cost became even higher than expected on account of unique solutions. Measuring stations are installed for running and maintenance, and for follow-up and evaluation. A reorganisation come to pass along the way, and the project has now been transferred from the planning department to the department for production for installations in the service building shown in Figure 3.

Analysis and conclusion

The steps requiring most effort from the project leaders in the process has been to design the practical solutions and finding suppliers. This was on the other hand expected as it is a unique innovative system that has not been tested earlier. Still, it is all about navigating within the frame for existing technique to achieve the advantage that the 4GDH with three pipe system solutions have.

Furthermore, the discussions on the practical problems with the separate heat exchange units for each flat in the multifamily buildings has been time consuming and has not yet led to any solutions. Motives for the municipality housing company to reject separate heat exchange units were that extra piping would diminish the rentable space and the questions about – who would own the shaft, who would own the pipes and who would get the insurance?

All decisions in energy companies and housing companies are impacted by the long-term perspective as they work with investments that will last for periods of 80 to 100 years implying that any decision will have long-term consequences. All companies also have local policies and/or action plans sustainability and for being fossil free in a near future. The plans include low temperature district heating as a priority and as one way of getting there.

These are the holdbacks found so far, hindering the opportunities of using the low temperature system 4GDH with three pipes. An easement, usufruct or even a three-dimensional property formation (SFS 1970:988 to SFS 2020:921) for separate shafts would likely solve the problems mentioned above. In this one instance the developer is not ready for novel systems. Moreover, there is a Swedish legal practice with precedent regarding district heating, and is called strict liability where the owner is liable for damages regardless of circumstances (NJA 1991: SFS 1972:207).

The conclusion so far may only apply for the process which unique character has delayed it more than six months. It could be considered normal though, in a project of this rank.

There are no legal holdbacks for 4GDH, and with time when this district heating solution has become more common with longer series of manufactured units and a more practical welding of pipes, if steel is still needed, simply when the technique is more adjusted to 4GDH the investment costs will also decrease.

An overall conclusion on the Ranagård project can only be drawn after completion, and commissioning and analysis of data from the different and already installed measuring stations, and after measuring the customers' habits and use of heating and hot water.

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