Technology Collaboration Programme
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IEA DHC

INTERNATIONAL ENERGY AGENCY
TECHNOLOGY COLLABORATION PROGRAMME ON
DISTRICT HEATING AND COOLING

SUMMARY FOR NON-TECHNICAL AUDIENCES

OPTIMISED TRANSITION TOWARDS LOW-TEMPERATURE AND LOW-CARBON DH SYSTEMS

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Miika Rämä. Within a heat accumulator facility (called the Heat Garden) in Torino, Italy.

Citation:

Please refer to this report as:

Rämä M, Abdurafikov R, Pursiheimo E, Svendsen S, Tunzi M, Sandvall A, Romanchenko, D, Salenbien R. OPTiTRANS: Optimised transition towards low-temperature and low-carbon DH systems. IEA DHC Annex XIII Report, 2023.

CONTENT

1 INTRODUCTION

The International Energy Agency (IEA) Technology Collaboration Programme (TCP) on District Heating and Cooling (DHC), including Combined Heat and Power (CHP) and its Annex XIII project "Optimised transition towards low-temperature and low-carbon DH systems" (OPTiTRANS), focuses on the practical barriers for developing DH into a low-temperature and a low-carbon system.

District heating and cooling (DHC) can play a key role in 1) decarbonisation of urban heating and cooling systems as well as 2) supporting the overall development of the low-carbon energy system. The first is accomplished by replacing fossil-based heat supply by the use of renewable, excess and natural heat sources, and by improving the system efficiency; the second by cross-sectoral linkages, providing flexibility through smart use of thermal storages, demand response and heat supply, e.g., CHP plants and heat pumps (HPs). Previous research has confirmed that a transition to efficient, fossil-free and flexible district heating (DH) is an essential tool in meeting the ambitious emission reduction targets needed for avoiding global warming over the 1.5-2 °C limit. A concept of 4th generation district heating (4GDH) encloses the needed elements and can be considered as a useful toolbox for the transition. A key aspect of the 4GDH concept is the lower distribution temperatures enabling the aforementioned new heat sources and improved efficiency.

Instead of the already-confirmed overall energy system level benefits, the focus of this proposal is on the DH company and DH system level; how to facilitate the transition process in practice and to ensure adequate support for long-term decision making. Developing DH means actions throughout its value chain; heat supply, distribution and building levels – while being mindful on what is taking place on an energy system level such as rapid increase of wind and solar based electricity production.

Project work addressing these themes is reported under four specific chapters: long-term modelling for transition towards future low-temperature systems (Chapter 2), operational modelling for low-temperature district heating (Chapter 3), digitalisation of demand side and motivation tariffs (Chapter 4) and building heating system operation (Chapter 5). In addition, the results are analysed from the perspectives of the project partner countries (Belgium, Denmark, Finland and Sweden) and finally generalised and summarised as a future outlook for countries with 1) developed DH systems and 2) the developing DH countries (Chapter 6). The aim of this country-specific analysis is to enhance the applicability of the project results, also demonstrating what role the operational environment can play in adopting DH technologies, practices and business models.

2 LONG-TERM MODELLING FOR TRANSITION TOWARDS FUTURE LOW-TEMPERATURE SYSTEMS

The focus here is on the heat sector and DH system at the local/city level to ensure adequate support for long-term decision making. The method of choice is dynamic energy system optimisation modelling and scenario analysis using TIMES (The Integrated MARKAL-EFOM System) model generator, addressing the following question from a city-level perspective in the long term: How are energy systems and system costs of different DH distribution temperatures compared? A model called "TIMES_CityHeat" (Figure 1) developed within IVL is used. The heating sector of a city is represented in detail, including existing individual heat boilers or devices in buildings and existing DH systems and DH distribution networks.

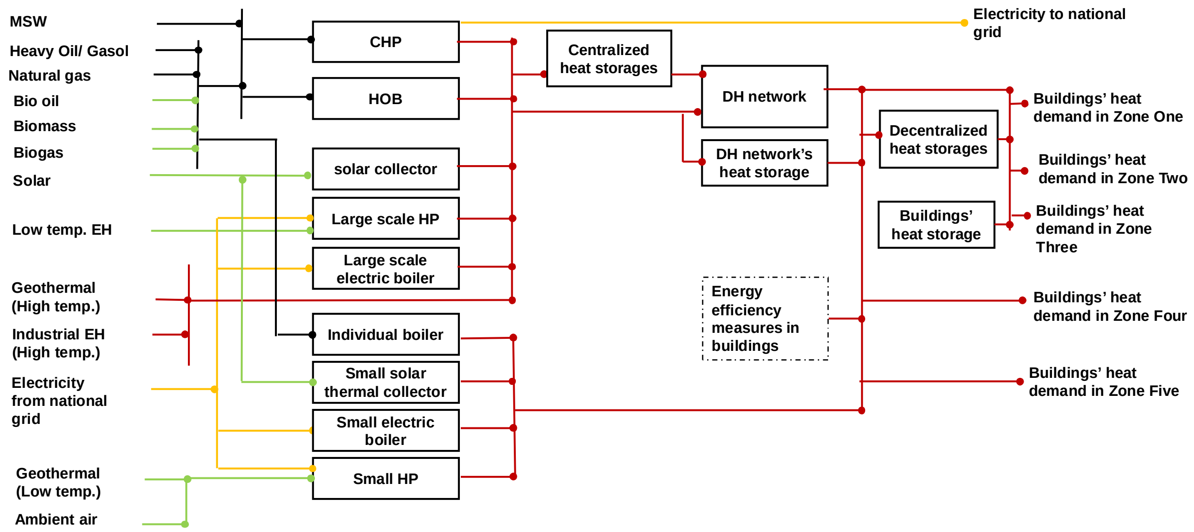

Figure 1. Schematic representation of the heat sector and interaction with the power system.

Three scenarios for different DH distribution temperatures are used; base (BASE), low return temperature (Lo Re), and low supply and return temperatures (Lo Sup & Re). A case study representing the city of Eskilstuna with an annual total heat demand of 3 500 TJ is selected. DH is the main supplier of the heat demand in the city, having a market share of 65%. The remaining heat is supplied by individual electric boilers (5%), ambient-air HPs (10%) and ground-source HPs (10%), biomass boilers (9%) and a very small share of solar thermal. The current DH supply of Eskilstuna comprises of a biomass-fired CHP plant, a biomass-fired heat only boiler (HOB), four bio-oil-fuelled HOBs and four oil-fuelled boilers normally used as a reserve capacity. Both the biomass units have flue gas condensation. Altogether, the plants have the capacity of 437 MW and 38 MW for heat and electricity, respectively. There is also a centralised heat storage tank (900 MWh). Current supply and return temperatures of the DH network are 75-100°C and 40-50°C, respectively. The DH network length is about 33 km.

The modelling results (Figure 2) indicated that DH demand is expected to drop dramatically between 2022-2027 due to assumption used for the build-up rate of re-construction of existing DH network, with individual heating (mainly ambient air heat pumps) taking over. Heat pumps are also the most common heat supply technology in the future. The dramatical drop is mitigated, to some extent, by the introduction of low-temperature district heating that lowers the total system costs compared to BASE scenario.

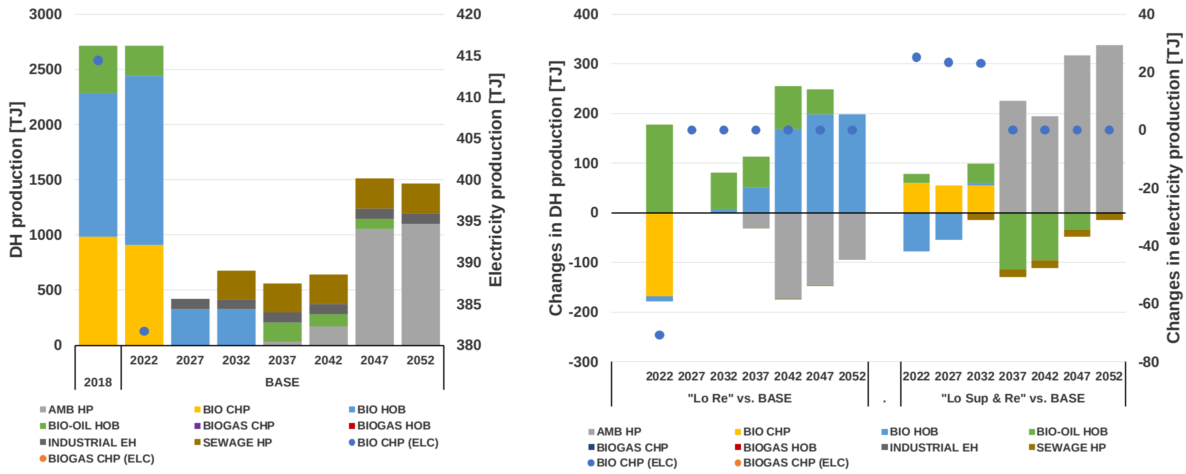

Figure 2. DH and electricity production in the BASE scenario (left), and their changes in the "Lo Re" and "Lo Sup & Re" scenarios (right).

The results show that the low-temperature DH distribution can contribute to the increased competitiveness of DH compared to individual heating solutions, suggesting that low-temperature DH distribution could be an important driver for DH development if heat demand of buildings in cities, like Eskilstuna, decreases due to the increased energy efficiency of both old and new buildings.

While the results are highly dependent on the initial assumptions and characteristics of a specific system (elaborated in more detail within the full final report), they demonstrate what conclusions a modelling exercise can provide. The questions to be asked are 1) can we generalise the results for another specific system possibly in another country and 2) what can we do to enhance the competitiveness of DH further? Leveraging the benefits of low-temperature seems to be the key, and enhancing the transition pathway could help in maintaining the DH market share.

Low-temperature DH distribution can also reduce CO_2 emissions associated with the power sector. Moreover, it can reduce system costs of a buildings heating. This, in turn, opens an opportunity for the energy systems to reach the global carbon-neutrality goal at a lower cost.

3 OPERATIONAL MODELLING FOR LOW-TEMPERATURE DISTRICT HEATING

Operational modelling tools are needed for assessing the impact of distribution temperatures and/or a more decentralised heat supply based on the utilisation of excess and renewable heat sources. An accurate assessment of the benefits of the low-temperature transition is crucial in finding the acceptable costs for implementing it. This is especially true for existing systems and also a very relevant aspect in the planning of new, next-generation DH systems. The main outcome of the work presented here is a model combining heat supply optimisation model based on linear programming (implemented using Julia[1] programming language, the JuMP[2] modelling package and run by Python) with a distribution network model (implemented using Apros® District). The basic approach is visualised in Figure 3. The motivation is simple; the low-temperature distribution improves the operational efficiency of virtually all heat supply options. On the other hand, managing the temperature level within the network is more challenging and can present additional constraints and costs for the heat supply operation.

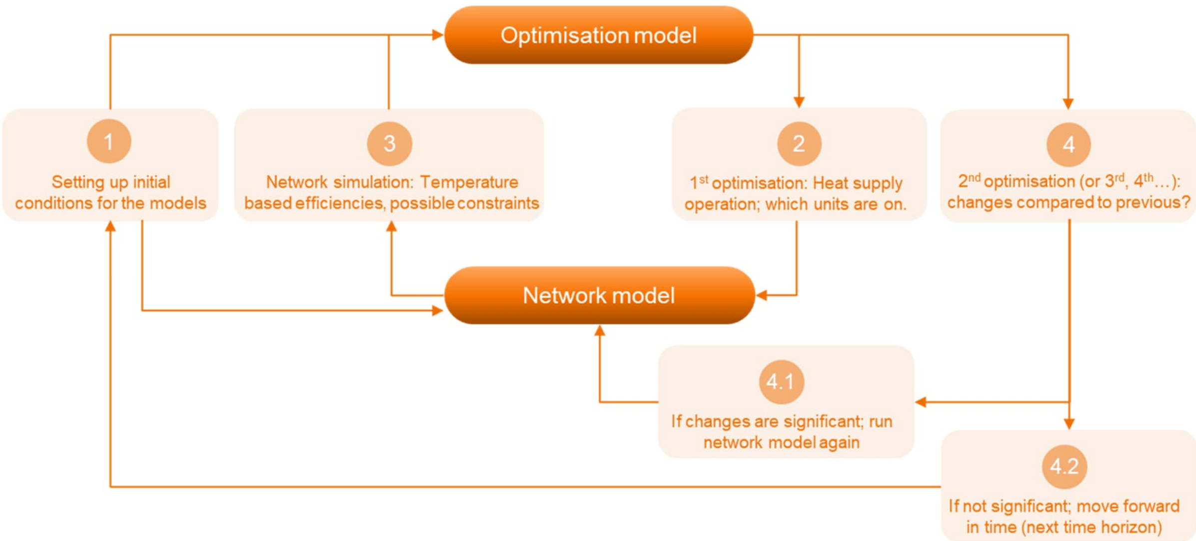

Figure 3. Basic principle of combining the optimisation and network models.

A case study representing the city of Lapua and it's city-wide DH system is used to develop, test and analyse the operation of the model. The Lapua DH system has a DH demand of 70 GWh with over 700 connected consumers and a peak demand of approximately 30 MW. The main heat supply unit is a CHP plant (4 MW electricity, 18 MW heat and a 2 MW flue-gas

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[1] The Julia Programming Language (julialang.org)
[2] JuMP | a modelling language and supporting packages for mathematical optimisation in Julia (https://jump.dev/)

condenser) with a number of heat-only boilers supporting. The system also has two third-party producers (a sawmill and another industrial site). The initial outlook indicated that the system is very suitable as a test case; it is both reasonably small, but still containing a versatile heat supply. As a low heat demand density system, it is also expected to experience challenges in introducing low-temperature distribution.

A total of three scenarios were studied. Firstly, the system with its current configuration, business-as-usual (BAU). Then, the BAU scenario with additional distributed HP capacity (BAU with HPs) located on the outskirts of the network. Finally, a scenario with the same additional HP capacity and low (65/30 °C) distribution temperatures (Low temp).

The initial expectations were that low-temperature distribution would greatly improve the feasibility of the HP based heat supply and would also be needed in order to maintain the temperature level in the outskirts of the network. However, while the HP did indeed benefit from the lower temperature levels, the main CHP unit with its flue gas condenser did so as well. In practice, the HP based capacity was mostly run only when needed, i.e. when local production was necessary to maintain the minimum supply temperature. The outcome was very sensitive to fuel price assumption as seen from Figure 4 below. With a 30 % increase in fuel price (equivalent to substituting 20 % of biomass with peat, assuming emission price of 90 €/t) already results in same full-load hours for both HPs and the CHP unit.

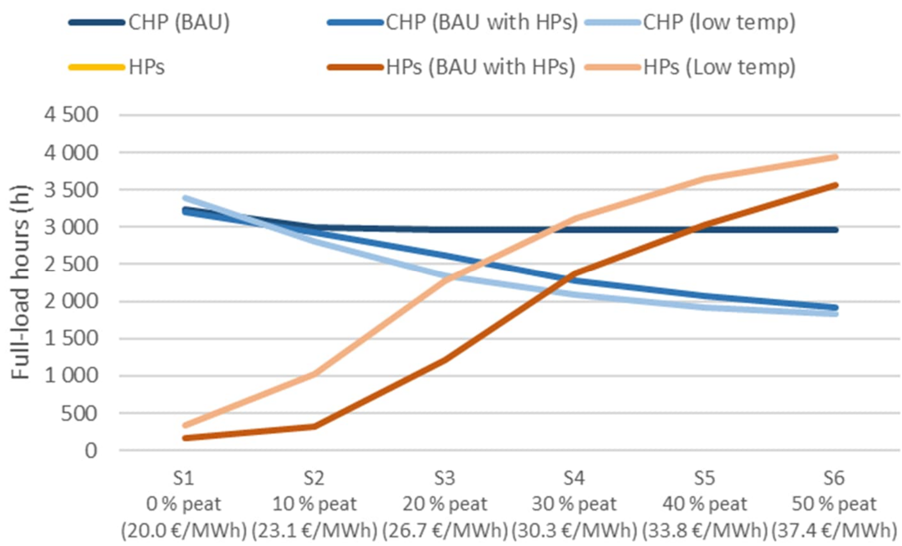

Figure 4. Full-load hours for the CHP unit and the HPs for all the scenarios with different peat content (and price) in fuel used by the CHP unit.

As a summary, the initial objective of combining traditional heat supply optimisation with a network simulation model was successful, but even smaller systems can be more complex than expected. E.g., a closer look at the network indicated that there is a need to also assess the pressure levels (pump control) as a possible constraint, not only temperatures.

4 DIGITALISATION OF DEMAND SIDE AND MOTIVATION TARIFFS

This section focuses on how digitalising the demand side can help secure the optimal, low-temperature operation of heating systems in existing buildings. Results from several case studies in Danish buildings complement the analysis including residential buildings, commercial buildings and domestic hot water systems. While the technical solutions and methods are essential, the end-user engagement is equally crucial. Additionally, the topic of the motivation tariffs is presented and discussed. They represent one of the most successful activities DH operators have adopted in Denmark to make end-users actively participate in the overall green transition of the entire district heating networks.

The study pointed out that there is significant potential to utilise lower temperature levels in building heat distribution system, without any major investment. It is common that the system is oversized, but more importantly they are not often operated as efficiently as possible. Two critical actions are required: a more uniform heat distribution among apartments that can only be stimulated by letting the end-users use all radiators if they want to achieve the expected comfort; and to diagnose and fix the incorrect settings and faulty components in the heating systems, using the operational data from the remotely readable digital meters and submeters. Moreover, the “design conditions” rarely occur in normal operation and correspond to a fraction of the cumulative energy consumption as shown in Figure 5. Hence, the large majority of the heating season, the supply temperatures in the networks can be as low as 55-60 °C.

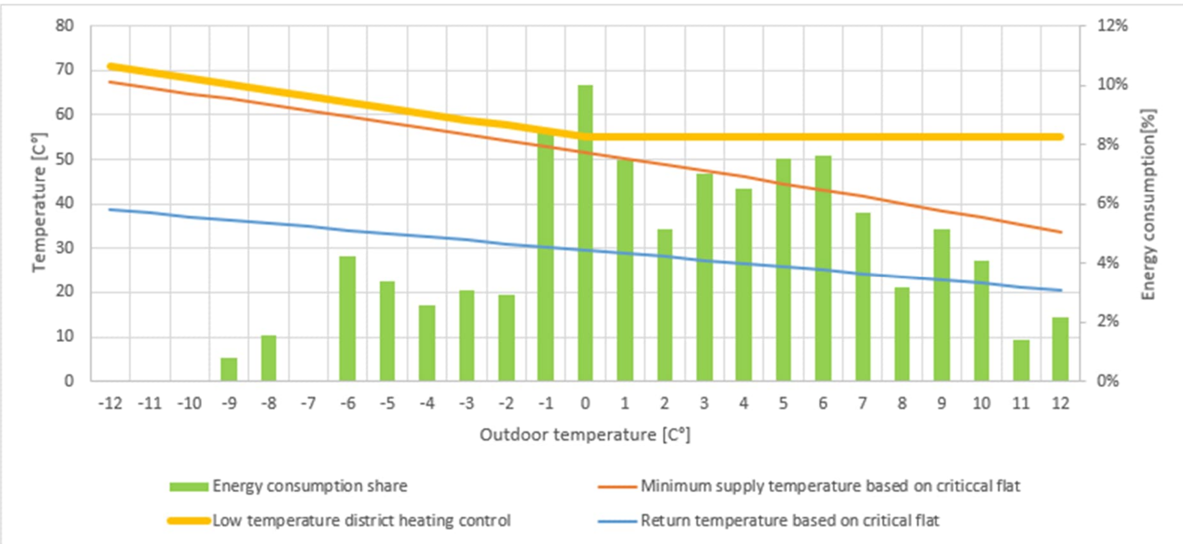

Figure 5. Minimised operating temperatures in a multi-family building and DH low-supply temperature control curve.

With the reduction of the supply temperature for the space heating systems, the DHW requirements to control the Legionella bacteria growth will define the limits for the minimisation of the supply temperatures in the DH networks. Here, innovative substation designs are needed. The proposed concept aims to decouple the hot water production from the reheating of the circulation flows by having two dedicated heat exchangers. Then the return temperature flows can be cascaded to the space heating systems or cooled by a booster heat pump. This can lead to return temperature in the range of 25-35°C.

Motivation tariffs are common practice introduced two decades ago by Danish DH operators and represent a success story, documenting two main things: the engagement with the consumers that have a financial incentive to improve the operation of their heating systems and be active actors in the sustainable transition of the community; and that it effectively contributes to reducing the operating temperatures in the networks. In the case of Viborg DH system since 2002, the temperature levels have dropped from 80/50 °C to 65/40 °C. This is fundamental in paving the way for the green transition of energy generation and sustaining the economic competitiveness in the district heating networks. Operators could also potentially introduce a more progressive motivation tariff, increasing the potential incentive to their consumers based on the future expected cost reductions. This could provide a greater impulse now to take action to improve the operation of the secondary side heating systems and components. Figure 6 represents the existing Viborg DH system motivation tariff scheme with three examples of different operating conditions fora single-family house (140 m^2, 14 MWh/year). Based on the current price structure, the end-users in Ex1 (high return temperature) would experience an increased heating cost of 8.5%; whereas Ex2 (low return temperatures) and Ex3 (low supply and return temperatures) would expect a discount in the heating cost of 4.5% and 22% respectively.

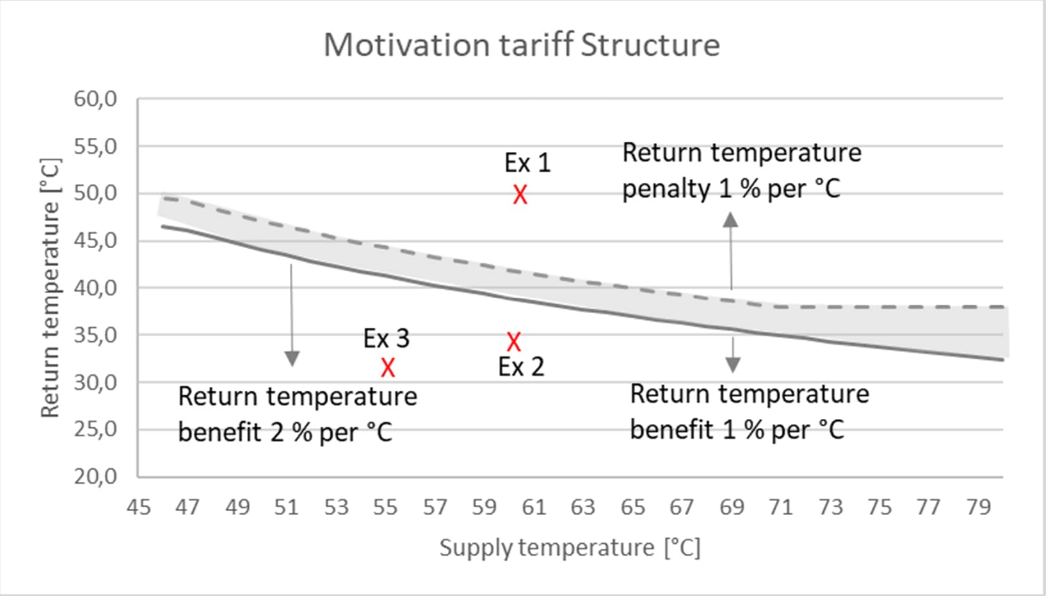

Figure 6. Viborg Varme motivation tariff scheme.

5 BUILDING HEATING SYSTEM OPERATION

Lower distribution temperatures in district heating systems, a key aspect of the 4GDH concept, are crucial towards enabling new heat sources and improved system efficiency. From a technological point of view, little challenge lays in decreasing the supply temperature. Moreover, recent progress has shown that much of the existing building stock could be operated under low(er) temperatures than the strict design specifications. However, reality is much more complicated and diverse than theory, and in district heating systems, it can typically be observed that the network return temperature is greatly affected by the performance of the buildings connected to it.

The ambition of this section is to illustrate that this is indeed the case for a typical office building that is considered to be well-operated. And also to experimentally show that low-cost and often unobtrusive measures in the building can help mitigate the negative effects on the return temperature. As a case study, the performance of VITO's headquarters building was analysed and optimised for low temperature operation.

Measurement equipment for thermal power (kW), primary supply and return temperatures (°C), mass flow (l/h), outdoor and indoor temperatures (°C) and bypass supply temperature (°C) were installed and studied during the project. Figure 7 illustrates the full overview of the data collected during the project duration.

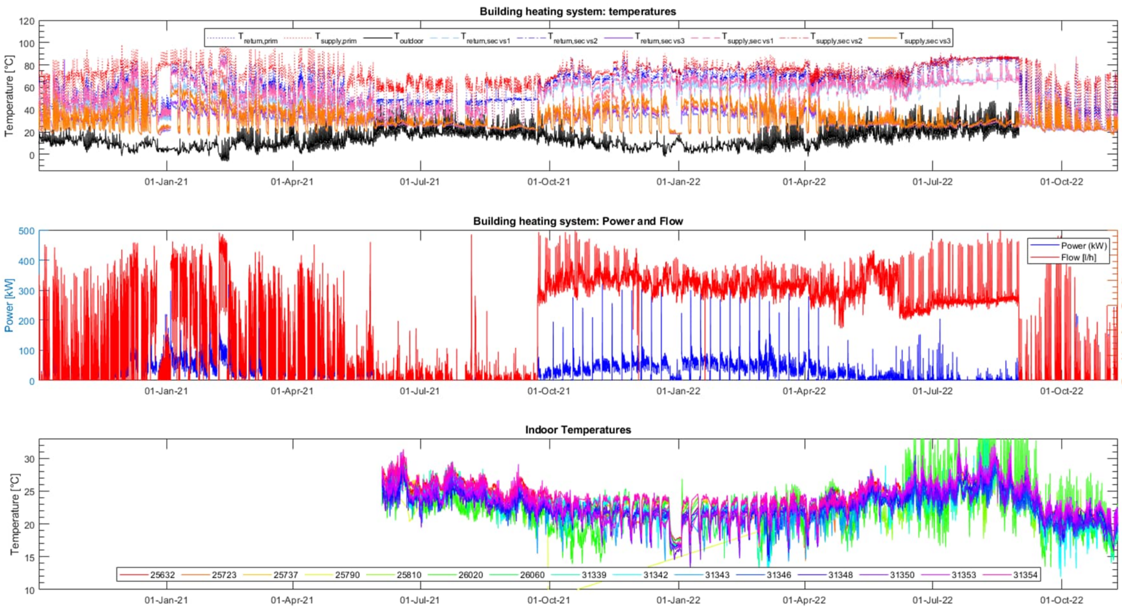

Figure 7. Full overview of data collected during the OPTiTRANS project duration. Top: building heating system temperatures. Middle: flow and thermal power across the primary heat exchanger. Bottom: indoor temperatures.

VITO, the Flemish institute for technological research, has its headquarters located in Mol, Belgium. The HKT building, designed and constructed in the late 1950's, can be seen as a typical office building that is still found throughout Belgium and abroad. Throughout the years, some common renovation actions have been taken and landscape offices have replaced the traditional single office layout during a major renovation in the early 2000s. The building is connected to the campus district heating grid, with separate heat exchangers to produce domestic hot water and space heating. There are two internal heating circuits connected to a bypass loop that ensures fast response times for the heating system. However, this comfort measure is very detrimental for the return temperature of the heating system.

Preliminary analysis of the system included recording the normal, classic operation of the system and the impact of the day/night setback. Experimental demonstrations focused on the bypass loop, lower operational temperatures, comfort issues, heating season start-up and installation and commissioning of a new building management system.

The work carried out represents a very practical point of view regarding the operation of a building heating system. The main objective was to demonstrate the effect that faults and suboptimal operation in either the substation or the building heating system can have on the return temperature towards the network.

Informing and educating the occupants on how to properly operate the heating system was part of the work. Also, systemic faults were identified and corrected (the so-called low-hanging-fruit measures). With the installation running optimally, an analysis was done on the typical performance of the heating system, as well as a look into the effect of continuous operation.

With the implementation of a new building management system, the heating curves of the system could be lowered while thermal comfort remained steady, as shown with the installation of indoor temperature measurement equipment. And importantly, the return temperature of both the building and DH network appear to be lower at the start of the heating season.

Hence, detection and correction of faults, either in hardware or in the way the system is operated, and correct control within that heating system can help mitigate the negative effects on the return temperature.

6 A FUTURE OUTLOOK FOR DEVELOPING DH

Here, the results of the project are considered from a future development perspective, and for both developed and developing DH countries. When and how would the results be applicable and what impact could they have?

6.1 COUNTRIES WITH DEVELOPED DH SYSTEMS

- Systematic mapping of new local heat sources, more specifically with regards to industrial and urban EH sources to replace biomass and/or fossil fuels.
- A tool that can provide optimal solution with a wide and long-term perspective. This is to avoid sub-optimal solutions that can occur due to only focusing on individual buildings and to limit the risk of lock-in effects due to the long lifetime of infrastructure.
- Lower DH distribution temperatures and existence of heat storages increase the competitiveness of DH systems compared to individual heat devices in buildings.
- Tools (operational and for long-term assessment) that accurately address both the optimal operation and temperature dynamics are essential for assessing the benefits of low-temperature distribution; more efficient integration of renewables and excess heat, and lower heat losses.
- Preparation of existing building stock to deliver the expected comfort with low-operating temperatures in parallel or prior to the assessment of investments. This will guarantee the robustness of the business model based on low-temperature heat sources.
- Enlarge the economic incentive from motivation tariffs to stimulate the investment inside buildings, accelerating the transition towards a renewable-based energy system.
- Empower the digital infrastructure to secure the integration from the different data and signals from sensors and remove the barriers and “silos” limiting the potential of the communication among all domains. Low-cost and practically oriented building heating system performance assessment. Anomalies can be detected and fixed easily, promoting user awareness when causes are visualised and quantified.
- Impact of night and weekend-setback operation on the network peak demand and indoor temperatures.
- Importance of proper training for building janitors or technical staff, who often rely on personal (potentially outdated) experience and risk-mitigation strategies.

6.2 DEVELOPING DH COUNTRIES

- Systematic mapping of new and low-cost local heat sources, such as industrial and urban EH sources, solar and geothermal potentials. Investment in network construction in more densely built urban areas can also promote DH utilisation.

- New DH systems need to be designed for low-temperature distribution. This provides an opportunity to maximise the utilisation of new heat sources and improve the overall economy of DH. Heat storages can also provide extra benefits to the DH systems.

- Applying a tool that can assess solutions with a wide and long-term perspective. This is to avoid sub-optimal solutions that can occur due to focusing only on individual buildings and to limit the risk of lock-in effects due to a long lifetime of infrastructure.

- Combining an optimisation model and a distribution network simulation model can provide a significant boost in assessing the true potential of DH. Adopting the approach will ensure a more efficient system and avoid the challenging transition process towards a low-temperature system if its benefits are not seen beforehand.

- Improve the effectiveness of long-term planning and optimisation tools by better integrating the specific local conditions that will affect the analysis and results. This will be fundamental in the emerging DH market.

- Start improving the heating systems operations in buildings and learn from the experiences of Nordic countries how to correctly design and operate those systems to be future-proof and ready to be operated with low temperatures. The removal of possible unnecessary by-pass flows as heritage from previous on-site supply.

- Consider integrating, given the country-specific legislation, a motivation tariff with bonuses or penalties. It is fundamental that the utility companies communicate transparently all the necessary information and provide technical support to end-users.

- Help building a secure and robust infrastructure to safely access data without breaching privacy issues. Metering can also be used for low-level fault detection.

- The performance of (existing) building heating systems is of crucial importance for new DH projects. Often, buildings are technically capable of low-temperature network operation even when designed for high-temperature operation. With the practical approach, they can be made suitable for new DH projects and markets at low cost and effort.

7 SUMMARY

The presented project focused on the practical barriers for developing DH into a low-temperature and a low-carbon system. The approach is aligned with the concept of 4th Generation District Heating (4GDH).

The project consists of research carried out on four interlinked themes: long-term modelling for transition towards future low-temperature system, operational modelling for low-temperature district heating, digitalisation of demand side and motivation tariffs and building heating system operation. The results were further analysed also from the perspectives of the project partner countries (Belgium, Denmark, Finland and Sweden), and finally generalised and summarised as a future outlook for countries with 1) developed DH systems and 2) the developing DH countries (summarised in previous chapter).

Work related to long-term modelling for transition towards future low-temperature systems was investigated through a case study for the city of Eskilstuna in Sweden. The results showed the impacts and advantages of DH distribution temperatures. Low-temperature DH distribution can contribute to the increased competitiveness of DH and be an important driver for DH development. In overall, the low-temperature DH can make an important contribution in helping the heating sector and the electricity sector evolve in a sustainable direction.

Work on developing an operational modelling tool for low-temperature district heating focused on combining a network simulation tool with an optimisation model. The motivation for the study was to provide tools to assess the impacts and benefits of the low-temperature distribution so that they could be compared to the possible costs of the transition, and to provide realistic constraints for the optimisation related temperature level management. The model operation was demonstrated and studied by a case example in the DH system within the city of Lapua in Finland. The defined test case showed the impact of the low distribution temperatures more accurately than before. The detailed investigation also showed that the network model can bring in additional constraints for the optimisation model related to managing the pressure levels. This represents a topic for further research.

Work focusing on digitalisation of the demand side and motivation tariffs showed that even the existing buildings and their systems can potentially cope with significantly lower temperature levels. Two critical actions can be identified: ensuring a more uniform heat distribution among apartments and diagnosing and fixing the incorrect settings and faulty components in the heating systems using data from the remotely readable digital meters and submeters. With the reduction of the supply temperature for the space heating systems, the DHW requirements to control the Legionella bacteria growth will define the limits for the minimisation of the supply temperatures in the DH networks. Here, innovative designs for the substations were presented.

The motivation tariffs can cultivate the development towards the more efficient operation. In the documented case of Viborg DH system, this has resulted in temperature levels dropping from 80/50 °C to 65/40 °C from 2002 to 2021. This type of development is fundamental in paving the way for the green transition of energy generation and for sustaining the economic competitiveness in the district heating networks.

This work on the operation of a building heating system from a practical point of view had the main objective of demonstrating the impact of faults and suboptimal operation in either the substation or the building heating system. These impacts show finally on the return temperature towards the network. As a concrete example, the heating system in a typical office building (VITO's headquarters) was analysed and optimised for low-temperature operation. The work showed that when addressed systematically, the heating curves of the system could be lowered while thermal comfort remained steady. Importantly, the return temperature of both building and DH network appear to be lower. The work also demonstrated the importance of the occupant behaviour and the practices of maintenance personnel. These need to be considered and addressed during the work.