

International Energy Agency Technology Collaboration Programme on
District Heating and Cooling including Combined Heat and Power

**Annex XII final report summary
for a non-technical audience**

**Integrated Cost-effective
Large-scale Thermal Energy Storage
for Smart District Heating and Cooling**

Project short title:

Large-scale Thermal Storage for District Heating and Cooling

May 15, 2020:

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This project has been independently funded by
the International Energy Agency Technology Collaboration Programme on
District Heating and Cooling including Combined Heat and Power
(IEA DHC).

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Executive Summary

Modern district heating and cooling (DHC) systems are a vital technology for the transition into a green economy. They enable the coupling of the heating and electricity sectors for increased flexibility of the overall energy system. In smart DHC systems, large-scale thermal energy storages (TES) allow for the integration of high shares of renewable energy sources (RES), with excess heat, with excess electricity from RES, and the optimization of combined heat and power plants (CHP).

The International Energy Agency District Heating and Cooling Technology Collaboration Programme (IEA-DHC) in its strategic research agenda include large-scale TES as central elements of future modern DHC systems.

The research completed in the IEA-DHC project 'Integrated Cost-effective Large-scale Thermal Energy Storage for Smart District Heating and Cooling' (IEA DHC Annex XII Project 3, Contract No. XII-03) contributes towards the development of data, information and analysis tools to encourage the use of cost-effective large-scale underground thermal energy storage (UTES) in DHC systems. The following three Task Reports have been issued as part of this IEA-DHC funded project. They can be found on the IEA-DHC web site:

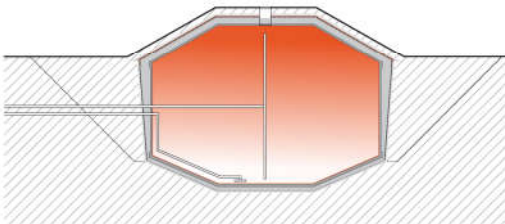
- Task A: Design Aspects for Large-Scale Aquifer and Pit Thermal Energy Storage for District Heating and Cooling
- Task B: Aquifer Thermal Energy Storage for Smart District Heating and Cooling - Technical report on model validation, cost data and results of an exemplary base case study
- Task C: Pit Thermal Energy Storage for Smart District Heating and Cooling - Technical report on model validation, cost functions and results of an exemplary base case study

Task A: Design Aspects For Large-Scale Aquifer and Pit Thermal Energy Storage for District Heating and Cooling

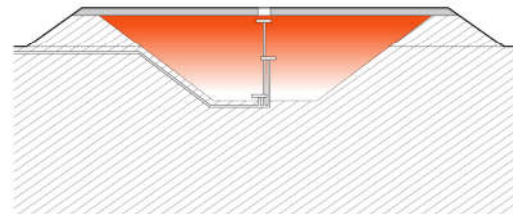
Four main concepts for large-scale underground thermal energy storage have been developed and demonstrated in the last decades, as shown in Figure 1. Each of these concepts has different capabilities with respect to storage capacity, storage efficiency,

possible capacity rates for charging and discharging, requirements on local ground conditions and on system boundary conditions. The TES technologies of interest for this IEA-DHC funded project are aquifer and pit thermal energy storage (ATES and PTES), where ATES use naturally occurring self-contained layers of ground water (aquifers) for heat storage and PTES are made of an artificial pool filled with storage material and covered by an insulated lid. These TES types offer increasingly cost-effective solutions for large-scale applications. Where applicable, these TES types have a significant cost advantage compared to conventional heat stores such as above-ground steel tanks. Cost levels of less than 50 €/m³ have been reached and are particularly interesting for DHC applications with a low number of storage cycles (e.g. long-term or seasonal storage of cold or heat).

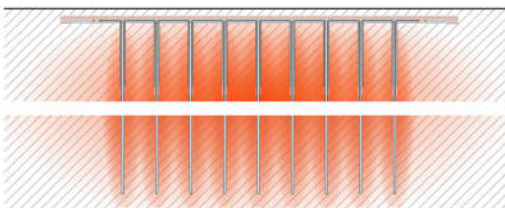
Tank thermal energy storage (TTES)
 (60 to 80 kWh/m³)



Pit thermal energy storage (PTES)
 (30 to 80 kWh/m³)



Borehole thermal energy storage (BTES)
 (15 to 30 kWh/m³)



Aquifer thermal energy storage (ATES)
 (30 to 40 kWh/m³)

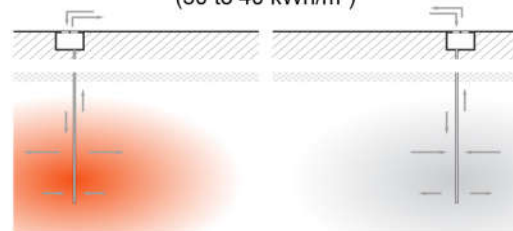


Figure 1: Overview of available underground thermal energy storage concepts

In the participating countries in this project (Canada, Denmark, Germany, The Netherlands and the USA) cost-effective concepts for large scale underground thermal energy storage, including ATES and PTES, have been developed in the last decades and realized in numerous projects. In the Task A report the authors' knowledge is compiled and summarized as follows:

- Design concepts for ATES and PTES; discussion of material aspects and lessons learned
- Description of typical application cases for these concepts, including design criteria and restrictions
- Overview of recently built projects with ATES and PTES in the partner countries, including concepts and integration details of the heat and cold sources or functionalities
- Cost analysis of realized projects
- List of technology suppliers and service providers at an international level

Task B: Aquifer Thermal Energy Storage for District Cooling

In the Task B report, a case study to assess the technical-economic potential of integrating a large-scale ATES system into a built-up community with an existing DHC|CHP is presented. The York University campus in Toronto, Ontario, Canada, has been used as the basis of this study. York University, the second largest university in Canada, was mainly selected due its significant cooling load, considered large enough to capture any benefit of economies of scale during the life cycle cost analysis of options.

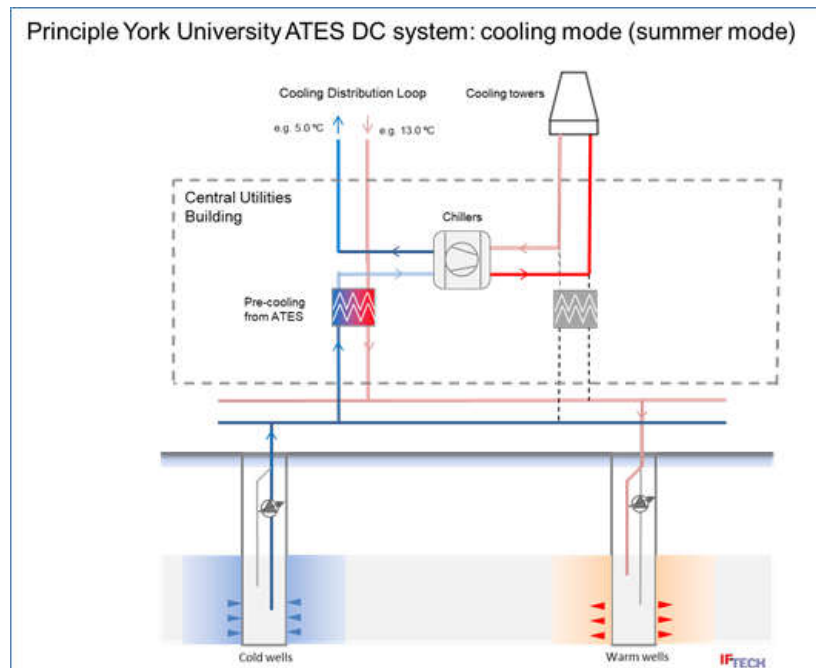


Figure 2: Integration of ATES system (discharging mode).

The York University study included a review, validation and documentation of the ATES dynamic analysis, and TRNSYS models used, as well as the development of a simple and robust model to characterize the University campus hourly cooling load. The design of four large-scale Aquifer Thermal Energy Storage (ATES) system options along with an approach for the ambient-cold dynamic charging of the ATES systems is proposed. Capital expenditures for the considered ATES system designs were obtained from local trades and drillers. While these costs are specific to the particular York University case study, they can be considered representative of North American electricity and aquifer UTES applications.

Eleven case study scenarios and system controls were considered for integrating ATES into the York University DHC|CHP system. The inputs, methodology used, and the results obtained from a detailed lifecycle cost analysis (LCCA) are presented and discussed in the Task B report. While the results of the LCCA are specific to the particular case of York University, the main lessons learned from the study on integrating large-scale ATES systems into existing DHC|CHP systems include:

- The various concept designs considered have excellent potential to reduce GHG emissions. For the particular case of York University, one integration scenario was found that it can substantially reduce GHG emissions from cooling by up to 85% with a reasonable 25 year investment rate of return of over 10%. This is achieved by switching the steam chillers from serving the base load to serving the peak load, thus substantially reducing their operating hours each year, while increasing that of the electric chillers.
- All sizes of ATES systems considered, whether configured with the steam chillers serving the base load or the peak load, show a positive, if sometimes modest return on investment.
- Using conservative capital cost estimates, the business case for employing an ATES system for the particular case of York University is relatively harmed by the fact that the proposed system provides only cooling, and not both cooling and heating, and due to the specific rate structure currently applied to York University for purchased electricity

For any educational, hospital or built-up community campus with an existing DHC|CHP system similar to the case of York University, and with similar hydrogeology and utility operational costs structures, results of the study suggest to also:

- Explore the potential of serving the campus heating load, in addition to the serving the campus cooling load, taking advantage and using the already accounted for ATES capital infrastructure. York University for example, experienced in 2019 a heating load of about four times more than the cooling load, 220,000 MWh compared to ~55,000 MWh of cooling load.
- Explore the impacts of a decision to operate the steam chillers to serve only during peak cooling load times.
- Pay specific attention to the structure of the utility costs, and more specifically electricity costs.

Task C: Pit Thermal Energy Storage for District Heating

A case study for a solar district heating (SDH) system with Pit Thermal Energy Storage (PTES) was completed and is presented in the Task C Report. A review and validation of the applied dynamic analysis, TRNSYS PTES simulation model is included. Validation results were derived by a comparison of modelled results with detailed measurements from two existing large-scale PTES plants in Denmark. Experiences from Denmark also form the basis for an investment cost analysis for PTES that was complemented with actual market prices for Germany.

A technical-economic analysis of a solar and biomass district heating system with integrated PTES was completed for a rural community in Germany, with a yearly heat demand of 7.8 GWh. The study included detailed dynamic system simulations and a profitability assessment. Three system variants with growing solar collector areas were investigated. Two of them consider a PTES, the largest one also a heat pump. The first base variant shows a typical solar thermal design for a full load coverage during the summer period, resulting in a solar fraction of 16.7 % of the total heat demand in the DH network. The second and third variants target larger solar collector areas resulting in solar fractions of 30.7 % and 50.4 %, but also disproportionately larger storage volumes compared to variant 1 as more solar heat has to be stored from the summer to the winter period.

Results of the case study indicate that the required solar collector areas for the three investigated scenarios are 2,600, 6,000 and 8,550 m² (aperture area), TES water volumes are 350, 12,000 and 17,500 m³. The resulting solar heat production costs (incl. subsidies) increase by a factor 1.5 from 44 €/MWh for scenario 1 and 66 €/MWh for

scenario 2 to 68 €/MWh¹ for scenario 3 for a three times higher solar share in the heat supply in case of scenario 3.

The case study for SDH with PTES can deliver valuable information for comparable small to medium scale DH networks in rural areas in Germany and abroad. The developed tools, data, procedures and study results can be adapted to other specific boundary conditions and used as a template for locations also in other countries.

The data, information and overall techno-economic methodology presented, has proven to be robust and could be considered by prospective DHC facility managers of similar DHC systems interested in cost-effective solutions for the reduction of carbon emissions and for assessing the potential of integrating large-scale ATES and PTES into existing DHC systems in an already built-up areas.

¹ this includes an assumed reduced heat pump electricity price; without this reduction the solar heat production cost is 83 €/MWh

This document is only a part of the results of the respective IEA DHC research project.

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