TU Delft

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Sustainable heating & cooling: the right heat, in the right place, at the right time, at the right temperature

Thermo-X

Challenges ahead and expertise available at TU Delft

TU Delft

The challenge

Towards sustainable heating & cooling: Deliver the right heat, in the right place, at the right time, at the right temperature!

Challenges for the Netherlands
Heating and cooling account for half of the global energy end-use. Currently, most of this energy is generated by fossil fuels. Replacing traditional heating and cooling sources by sustainable alternatives will boost the energy transition and contribute significantly to achieving CO_2 reduction targets.

While a global challenge, the energy transition has become a particularly urgent challenge in the Netherlands for a number of reasons: the exploitation of the Groningen natural gas field is being wound down to prevent further earthquakes, rising sea levels pose a long-term threat to the country as a whole. Recognising the urgency, the Dutch government supports the Paris agreement which targets a significant reduction of the CO_2 emission (–20% in 2020, –49% in 2030) and an increase in renewable energy share from the current 6% to 14% in 2020 and 27% in 2030 for the Netherlands.

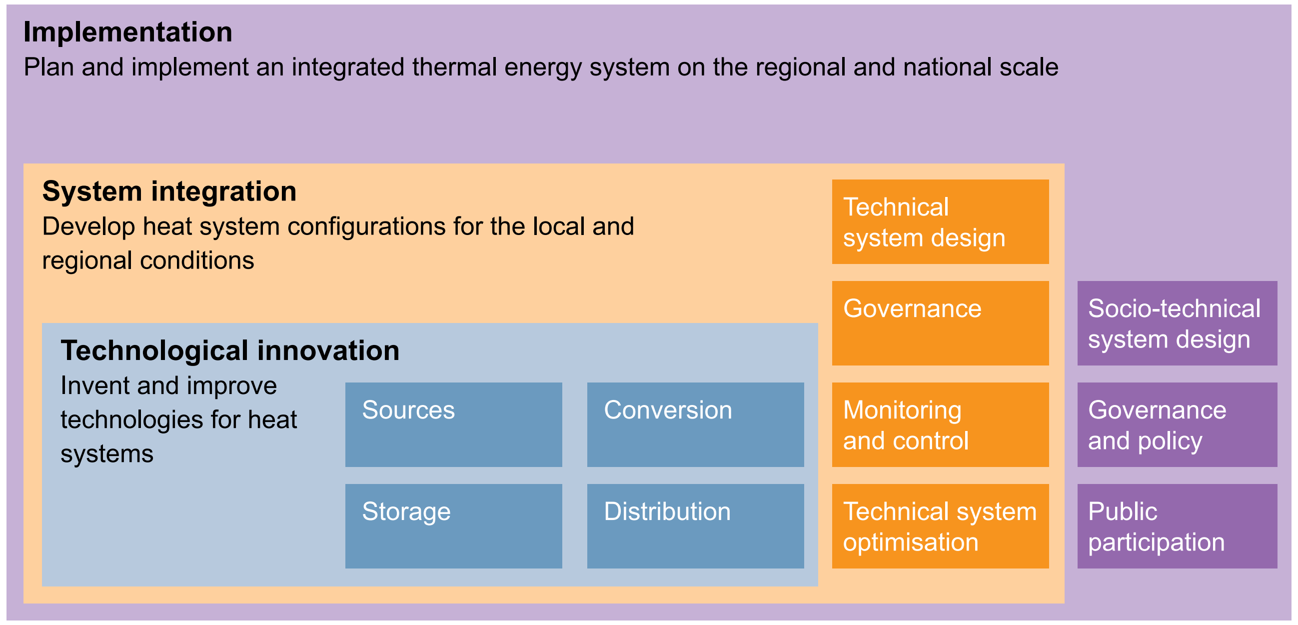
All these arguments are putting the challenges of achieving sustainable heating and cooling on top of the Dutch energy transition agenda.

In the light of the global energy transition, the concepts of heating and cooling need to be radically reimagined. For example, in moderate climates and industrialised areas, both heating and cooling capacities are abundantly available but often not in the right location, at the right time and/or the right temperature.

TU Delft developed a comprehensive research programme encompassing all aspects needed to design innovative future-proof integrated thermal systems. Studying the entire heat system requires an interdisciplinary approach, with expertise from social sciences and humanities, engineering, and technological disciplines.

The research programme is clustered in three challenges:

- Plan and implement an integrated thermal energy system on the regional and national scale.
- Develop heat system configurations for the local and regional scale.
- Invent and improve technologies for sustainable heat systems.



The three challenges all tackle technological as well as societal aspects. As they cover different scales of the energy system, the mix of technical and societal disciplines involved varies; the larger the scale of implementation, the more societal challenges come into play.

TU Delft's thermal energy research addresses two of the four main energy transition pathways identified by the Dutch government: (1) low-temperature heating, addressing the built environment and horticulture, and (2) high-temperature heating, addressing the industry. It also has strong links to the two other pathways (mobility; light and electric power) due to the required electrification of large parts of the heating and cooling system.

Implementation challenge

Plan and implement an integrated thermal energy system on the regional and national scale

This challenge addresses the 'bigger picture'. Researchers investigate the effect of demand and supply in local systems on the regional and national heat system, in such a way that the heat system can be optimised on a national scale. The challenge also has a strong societal component concerning the governance conditions and policy instruments required for a proper embedding of future heat systems in society at large.

- **Socio-technical system design: Design future-proof, sustainable scenario's and develop methods and models for informed decision-making based on an analysis of the current energy system.**
  Topics: *Availability of heat sources, choice of sources and technologies to respond to demands, centralised versus decentralised systems, dealing with uncertainty, cost-benefit analysis, agent-based modelling, business models.*
- **Governance and policy: Develop effective and efficient policies, governance arrangements, and financial-economic, legal, social and communicative instruments to support the implementation of a chosen thermal energy system.**
  Topics: *Ex ante policy analysis, policy scenarios, institutional analysis, governance, ethics, performance measurements.*
- **Public participation: Develop effective procedures and arrangements to engage stakeholders such as local communities, 'prosumers' and end-users in the transition.**
  Topics: *Social innovation, social risk management, stakeholder analysis, approaches for engaging citizens, participatory research methods, constructive technology assessment, action research, living labs.*

Community engagement and communication in geothermal energy projects
Energy technologies such as wind farms, shale gas and solar parks can cause public controversy. In the RESPONSE project, TU Delft researchers study public-private decision-making processes for (potentially) controversial energy projects. RESPONSE starts from the proposition that controversies are a source of information, as they articulate the conflicting values at stake and reveal unanticipated societal and ethical risks and associated costs and benefits. The aim of the project is to support decision-making for socially responsible energy projects.

Ultra-deep geothermal energy (UDG) is one of the technologies studied. In the Netherlands, there are currently seven UDG pilot projects; one of these projects is being studied using an anthropological approach. TU Delft's main research interests focus on how community engagement and (public) communication are designed and implemented in the early stages of formal planning and decision-making of a new technology such as UDG.

Acceptable design for heating systems
New technologies are being introduced to heat the built environment in a more sustainable manner. But end-users and other stakeholders do not always find these alternative heating technologies acceptable. Because of their concerns, public and semi-public authorities are unsure whether they should invest in the new heating systems. They need to consider not just the monetary costs and benefits but all factors that influence the acceptance of new technologies. TU Delft investigates these factors and examines whether public support can be increased by designing more equitable heating systems, both in terms of technical aspects and socio-ethical and institutional aspects. They also look at the division of responsibilities between the relevant authorities.

The research direction aims to achieve the following innovations:

- A theoretical framework for understanding the impact of technical, individual and institutional factors on the acceptance of public-private systems.
- A more comprehensive social cost-benefit analysis (SCBA), including acceptance by citizens.
- A dashboard through which decision-makers can simulate and analyse, for different local situations, which combinations of technologies and division of responsibilities between relevant authorities are acceptable to end-users and other stakeholders.
- An approach aimed at increasing the acceptance of new heating systems among this group by involving them in (SCBA) design sessions.

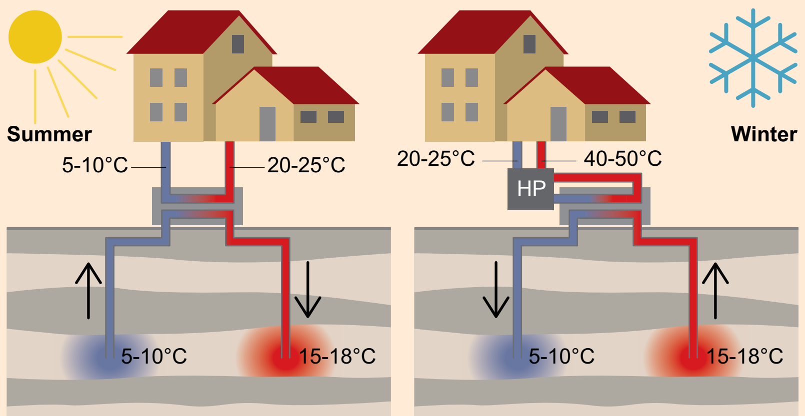
System integration challenge

Develop heat system configurations for the local and regional scale

This challenge involves the heat system as a combined system of technologies, implemented in households, utilities, horticulture and industry. Researchers working on this challenge are dedicated to finding robust configurations optimised to local and regional solutions.

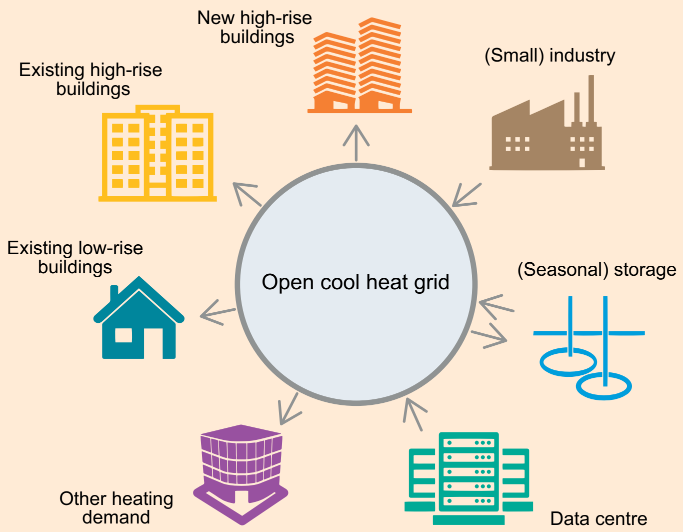
- **Technical system design: Develop the technical design for integrated, flexible and robust configurations suited for local and regional conditions.**
  Topics: *Type of houses, available heat sources, individual versus collective sources, making optimal use of sources in adjacent application areas (industry/horticulture/built environment), open low/medium-temperature heat grids for decentralised sources, life-cycle analysis, exergy analysis.*
- **Governance: Design efficient and effective structures to implement and govern future heat systems.**
  Topics: *Participation of stakeholders (e.g. suppliers, distributors and end-users), develop tools to choose between regulated versus incentive-driven heat demand and supply.*
- **Monitoring and control: Develop real-time monitoring and control systems.**
  Topics: *Smart home appliances targeting multiple levels (i.e. energy use, comfort, air quality and costs), big data for real-time performance assessment, privacy by design, smart heat grids.*
- **System optimisation: Optimise heat system configurations in the operational phase.**
  Topics: *System analysis, identifying innovative future technologies needed to achieve optimal system performance.*

ATES smart grid
Groundwater reservoirs, aquifers, provide opportunities to store heat in summer (cooling), extracting it again in winter (heating). As an energy-saving solution, aquifer thermal energy storage (ATES) is a cheap technology with short payback times. With only a small fraction of utility buildings in the Netherlands using ATES systems, the subsurface space utilisation has already grown to congestion levels in many urban areas. Interaction among nearby ATES systems introduces many design and operational uncertainties. To utilise the full potential of the available subsurface for ATES, a new framework for governance and control of ATES systems is needed. The solution under development at TU Delft provides an operational framework to decide on the adoption and use of ATES based on the current state of the subsurface. The decision framework facilitates exchange of information and includes model predictive control. With the information provided, current and future users can adjust their own ATES operation via a controller and compensation measures. In order to arrive at a proof-of-concept, expertise and models from different fields are combined: administrative policy and decision making (agent-based modelling), systems and control (distributed stochastic predictive control), and geohydrology (numerical models for fluid flow and heat transport in porous media).



Connecting sources with demands in 'cool heat grids'
In the built environment, many heat sources are available at temperatures between 15 and 30°C, such as waste water, surface water, cooling from supermarkets or datacentres, and solar thermal energy. Many heating and cooling demands in the built environment are in the same temperature range. In the KoWaNet project, TU Delft develops smart thermal heat grids that connect sources and demands in an intelligent way. These smart and open 'cool heat grids' will optimally connect all users – producers, consumers and those who do both – in order to efficiently deliver sustainable, cost-efficient and secure heat or cold. The exchange between different building functions makes the system rely less on external sources of heat or cold.

Apart from the optimal configuration and operational strategies of the grid itself, researchers also investigate the heating and cooling systems of connected buildings. They investigate the best options for the supply of hot water as well as ways to ascertain that building energy systems support the optimal operation of the overall grid and vice versa. Cool heat grids will be applicable to both new and existing urban areas, providing a possibility to locally balance the energy system as much as possible.



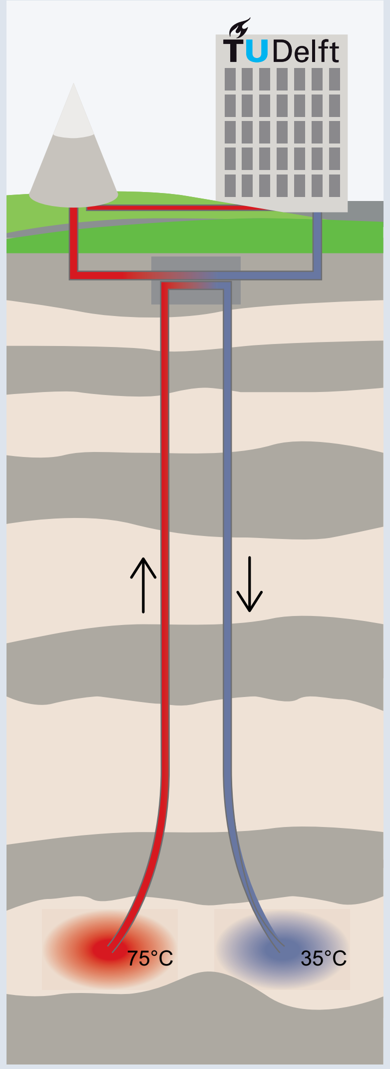
Technological innovation challenge

Invent and improve technologies for sustainable heat systems

This challenge focusses on the technological components of the heat system. It follows the approach of responsible innovation, taking into account effects and potential impacts on the environment and society. To achieve a 100% renewable energy system, multiple technologies must be combined. The efficiency of existing technologies needs to be improved and innovative new ones developed.

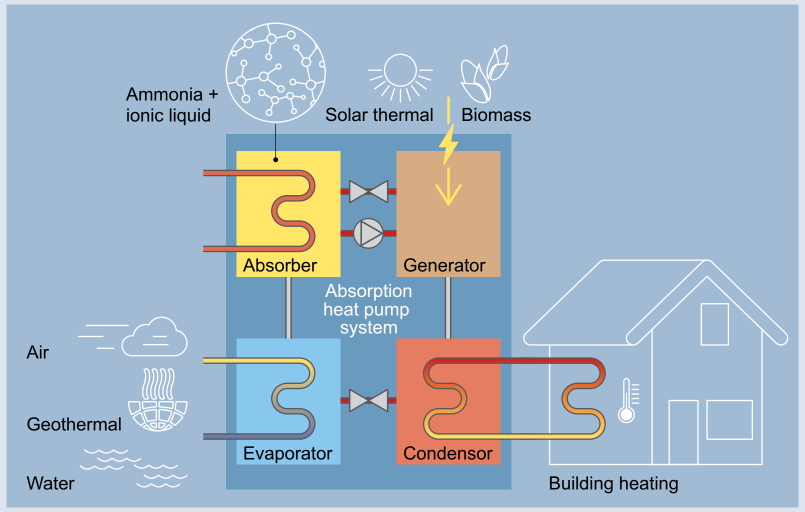
- **Sources**
  Topics: *Ultradeep geothermal (UDG), geothermal exploitation, surface water and wastewater as thermal sources, new fluids for solar to heat.*
- **Storage**
  Topics: *Aquifer thermal energy storage (ATES), high-temperature ATES, phase-change materials (PCM), thermo-chemical materials (TCM).*
- **Conversion**
  Topics: *High-performance heat pumps, heat to power, power to heat.*
- **Distribution**
  Topics: *Innovative materials, innovative installation methods in existing urban areas.*

Geothermal well doublet on TU Delft campus
Geothermal energy is thermal energy withdrawn from the earth. Through so-called geothermal well doublets, warm water is extracted from subsurface reservoirs and cooled water injected back. This is an attractive option to heat buildings and green houses, as it is a year-round, steady heat source. Although the number of geothermal well doublets has been increasing over the last years, limited understanding of subsurface processes often leads to operational problems such as reduced flow at the injector well or corrosion and clogging of installations. These effects result in sub-optimal exploitation of the resource and potentially in technically and/or economically failed facilities.
To solve those issues, TU Delft researchers propose to construct a geothermal well on campus that is equipped with surface and downhole sensors and uses novel composite casing material. The proposed doublet is intended to function as a heat source for campus buildings and, at the same time, as a living lab for research into the fundamental causes of operational problems, as a unique opportunity to develop and test technical solutions in a realistic urban environment.
TU Delft researchers aim to trace the travelling cold front using geophysical techniques, optimised by improving the predictive power of flow models. Chemical analysis of geothermal fluids will reveal insights into their interaction with reservoir rocks and technical installations. Additional insights into the subsurface processes and improved models and concepts will lead to optimised operations and a better prediction of the lifetime of geothermal doublets. This is an important aspect towards up-scaling of geothermal operations.



Highly efficient heating and cooling with absorption heat pump technologies
Vapour absorption heat pumps are thermally driven heat pump systems. They are used to transfer thermal energy from a heat source to a heat sink. Compared to conventional boilers, they are highly efficient systems to heat buildings. A properly selected refrigerant-absorbent working fluid inside a loop realises similar functions as a mechanical compressor: to vaporise and circulate fluid for continuous heating or cooling. The sustainability potential of absorption heat pumps has been rediscovered only recently. They can be integrated with a wide spectrum of low-grade and renewable heat sources, such as the exhaust industrial heat, concentrated solar thermal energy, and heat from biomass incineration.

To improve the energetic efficiency of the system and to overcome drawbacks of traditional working fluids, new materials have been introduced.



At TU Delft, the concept of using ionic liquids as absorbent and ammonia as refrigerant is being analysed. Ionic liquids are room-temperature molten salts with high boiling points and good affinities with refrigerants, and can be tailored for specific applications. Multi-scale evaluations are ongoing to understand the thermodynamics and heat/mass transport aspects. These include:
- Molecular simulations to predict the properties of ammonia-ionic liquid working fluids.
- Assessments of vapor-liquid equilibrium models applied to ammonia-ionic liquid working fluids.
- Modelling and experimental studies of the heat and mass transfer performance.

In addition, the new systems are used in demonstration projects for applications in the built environment and industry.

Available expertise at TU Delft

Social Sciences and Humanities

- Sociology
- Psychology
- Anthropology
- Policy and planning
- Agent-based modelling
- Social innovation
- Social cost-benefit analysis
- Social risk management

Natural Sciences and Engineering

- Energy potential mapping
- Life cycle assessment
- Exergy analysis
- Fluid dynamics
- Optimisation and control
- Monitoring and control
- Thermodynamics
- Heat transfer
- Geohydrology
- Geomechanics
- Building physics

Open invitation

With this document, the Thermo-X programme of TU Delft presents its vision and available expertise on thermal energy systems. We invite fellow scientists and stakeholders to share their vision and ideas to come to an ambitious national R&D programme towards sustainable heating and cooling, encompassing top-notch knowledge and facilities across all disciplines involved.

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