Digitally-Supported Smart District Heating

HEAT 4.0

Final (extended) report

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J. nr. 8090-000046B

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Contents

1. English preface

The current document is an expanded version of the official 'Final report' to the Innovation Fund Denmark (J.no. 8090-00046B) that is kept in schematic form, representing a short description of the HEAT 4.0 project, its organisation and its results. The current report gives an expanded version of the same content. It is not a complete survey but rather the best possible effort at present time. You may find much more in the linked resources, especially the scientific papers listed at the end of this report.

HEAT 4.0 is characterized by the 'cognitive model' where a given system can be seen as 'a sum of its components' versus 'a whole' (holistic system). Also, system complexity must be addressed and related in this cognitive model, including the application of mathematical models that are the basis for many of the services delivered by HEAT 4.0. HEAT 4.0 focuses mainly on digital aspects, combining various digital solutions into a holistic digital framework. This idea was strongly inspired by previous research and innovation work where the principles of 'converging technologies' and experiences of cooperation between involved partners and leadership, were developed and tested.

The 'Energy Lab Nordhavn' project did target the complexity of energy systems at the 'district level'[1], combining the sub-systems for electricity with thermal grids, involving amongst others, local storage capacities, the buildings and its consumers[2]. The main take away from this project with respect to district heating where a) a recommendation towards price differentiation for district heating, eventually localised, b) electricity as a sources for district heating ought to be adjusted in regulations, c) municipalities and utilities ought to be active in providing energy data for the solution providers, d) energy planning and building efficiency ought to go hand in hand at early planning stage, e) a recommendation on increased integration between energy networks (concrete el-net and DH networks), f) boosting with local electrical heaters ought to be considered, g) data-intelligent methods for forecasting and control ought to be increased, h) smart building management systems ought to be applied and their design ought to be able to support interoperability and controls ought to combine the different parts of the heating and cooling, i) experimental zones with experimental regulatory frameworks ought to be implemented to path the way for innovation, opening the entrance of innovative solution into the market, and last not least j) users ought to be involved in all aspects of the smart cities (Nielsen et al., 2020).

The highest system complexity for such similar research and innovation projects was targeted in 'CITIES', a project also supported by the Innovation Fund Denmark, where the 'system in focus' was expanded to whole cities, like Copenhagen, Malmö and other Scandinavian cities. In theory, the system boundary was extended to involve all utilities, mobility services, communication networks and even the impact of organisation and the city citizens. The impressive list of results from the project can be found in (Madsen et al., 2021)[3]. The results were manyfold and widely spread in topics. The take away from this project were defining, amongst other experiences, the HEAT 4.0 project content. One very important finding from CITIES was, to go for very practical implementation and research results, bringing them from an academic level to a market level. A first such attempt was already been carried out by the CITIES-initiated 'Smart Cities Accelerator' project, a European-financed research project with a focus on implementation.

From this wide range of possibilities, the focus of HEAT 4.0 was defined to be the innovation and implementation of digital services and solutions, inspired by the 'Industry 4.0' concept, adjusted to the district heating sector. The goal was to implement ideas from both large and small industries but also start-ups. Compared to the previously mentioned projects that were led by research organisations, the HEAT 4.0 project is managed by industries that strength

[1] A logic part of a city [https://en.wikipedia.org/wiki/City_district], in this case the district 'Nordhavn' in Copenhagen and others.
[2] Other energy system and grids, e.g. gas grid could be involved.
[3] https://smart-cities-centre.org/ 29 recommendations from the CITIES partners – direct link https://smart-cities-centre.org/wp-content/uploads/CITIES-Recommendations_april7_2021.pdf.

the transformation of research results into commercial solutions. As we will see, this limited not the research impact of HEAT 4.0 which also can document the large range of research results.

The HEAT 4.0 project was granted in February 2019 under the J.no. 8090-00046B by the Innovation Fund Denmark under the programme Grand Solutions.

The full title is: HEAT 4.0 – Digitally-supported district heating

NIRAS, as the main applicant and project leader, was new to Innovation Fund Denmark under the Grand Solutions Grant programme. In the application process and during the project, the experienced project leader, Alfred Heller, with a position as Assoc. Prof. at DTU and in the previous role of Vice Centre Leader in the CITIES project was elected as HEAT 4.0 project leader. He also was a leader and member of numerous national and international research and innovation projects. Management and the organisation of the project are described in detail below.

The Steering Committee, the authoritative organisation of the project, was assembled by very experienced leaders of the partner organisation, hereby ensuring commitments to the project at the highest level by partners, balancing commercial, innovative and scientific ambitions as well as leading guides for the project. More information on the steering committee and its work can be found below.

Communication between partners was managed through an established SharePoint website (limited access) and electronic mail. Every month a so-called 'HEAT 4.0 Monthly' was applied for knowledge sharing – physically at the beginning of the project and virtually during the time of the Covid-19 pandemic. These meetings were often used for internal communication and project alignment, later to share findings, products, results and others between partners and their involved personnel. All these sharing sessions were recorded and distributed through the internal HEAT 4.0 SharePoint website. You will find the most informative recording on the HEAT 4.0 website at https://heat-man.dk/events/ under the headings "HEAT 4.0 Monthly" meetings.

Concrete work was handled, organisationally in what we called 'Actions' where 'Workshops' and meetings were the way of working across partner organisations. Actions could consist of various combinations of partners and change dynamically, according to demands. The involvement of the leadership in these activities was optional and also dynamically organised. In some cases, the leadership was involved to gain insights or solving challenges. This way cross-activity and cross-work packages, knowledge collection/sharing and communication were facilitated in the daily work.

The current final report lines up the results and findings of the HEAT 4.0 project, balancing the demand for reporting to the funding organisation of HEAT 4.0, the Innovation Fund Denmark, under the journal number J.nr. 8090-00046B, and the relevancy for readers from the private and public sectors, innovators and researchers. Enjoy the reading and learning.

2. Dansk forord (Danish preface)

Dette aktuelle dokument er en udvidet version af den endelige rapport til bevillingsgiveren, Innovationsfond Danmark. Denne endelige rapport er udformet i skemaform og er vanskelig at læse. Derfor er nærværende rapport skrevet i en mere narrativ form der kort form præsenterer HEAT 4.0-projektet, dets organisation og resultater. Rapporten er ikke en komplet undersøgelse, men derimod den bedst mulige indsats på nuværende tidspunkt. Der findes meget mere information i de oplyste kilder, især i de videnskabelige artikler, der er anført i slutningen af denne rapport.

HEAT 4.0 er karakteriseret ved den 'kognitive model', at et givet system kan ses som 'en sum af dets komponenter' versus 'en helhed' (holistisk). Systemkompleksitet skal derfor ligeledes inddrages i denne kognitive model. HEAT 4.0 er hovedsageligt fokuseret på digitale aspekter og kombinerer forskellige digitale løsninger til en holistisk digital ramme. Denne idé var stærkt inspireret af tidligere forsknings- og innovationsprojekter, hvor principperne om 'konvergerende teknologier', erfaringer ift. samarbejde mellem forskellige involverede partnere og ledelse, blev udviklet og testet.

Energy Lab Nordhavn[4]-projektet var rettet mod kompleksiteten af energisystemer på distriktsniveau ved at kombinere delsystemerne som el- og det termiske fjernvarmenet, der blandt andet involverer lokale lagerkapaciteter, bygningerne og dets forbrugere. Det vigtigste fra dette projekt i forhold til fjernvarme er: a) en anbefaling til prisdifferentiering for fjernvarme, eventuelt lokalt bestemt, b) elektricitet som kilde til fjernvarme bør reguleres i et regulativ, c) kommuner og forsyningsselskaber bør deltage aktivt i at levere energidata til løsningsudbydere, d) energiplanlægning og bygningseffektivitet bør gå hånd i hånd i et tidligt planlægningsstadium, e) en anbefaling om øget integration mellem energinetværk (beton el-net og DH netværk), f.) 'boosting' med elvarme i lejlighederne bør overvejes, g) dataintelligente metoder til prognose og kontrol bør øges, h) intelligente bygningsstyringssystemer bør anvendes, og deres design bør kunne understøtte 'interoperabilitet', og styringen bør kombinere de forskellige dele af opvarmning og afkøling, i) forsøgszoner med eksperimentelle regulatoriske rammer bør implementeres for at muliggøre en innovation proces, og åbne op for innovative løsninger til markedet, og sidst ikke mindst j) brugere bør involveres i alle aspekter af "Smart Cities" (Nielsen et al., 2020).

Den højeste systemkompleksitet for sådanne lignende forsknings- og innovationsprojekter var målrettet i CITIES[5] , et projekt også støttet af Innovationsfonden Danmark, hvor 'systemet i fokus' er hele byer som København, Malmø og andre byer. I teorien er systemgrænsen i sammenligning med de andre projekter blevet udvidet til at involvere alle tekniske og organisatoriske netværk, bl.a. alle energinet, transportnet net der skabes af at byens borgere involveres. Den imponerende liste over resultater fra projektet kan findes i (Madsen et al., 2021)[6]. Resultaterne var mange og spredte over mange emner og technologier. Man høstede stor erfaring fra dette projekt, hvor man blandt andet også definerede dele HEAT 4.0-projektets indhold. En meget god læring fra projektet CITIES var vigtigheden i at gå efter mere praktisk implementering af de forskellige forskningsresultater, således at de bliver bragt fra et akademisk niveau til et markedsniveau. Et første forsøg på det blev allerede udført af 'CITIES Smart Cities Accelerator'[7], et europæisk finansieret forskningsprojekt med fokus på implementering.

Ud fra dette brede samling af muligheder blev fokusset for HEAT 4.0 defineret til innovation og implementering af digitale tjenester og løsninger til fjernvarmesektoren, inspireret bl.a. af 'Industry 4.0', et koncept til digitalisering af bl.a. industrielle processer. Målet var at implementere ideer fra både store og små industrier men også fra startups. Sammenlignet med de tidligere nævnte projekter, der blev ledet af forskningsorganisationer, ledes HEAT 4.0-projektet af

[4] Energy Lab Nordhavn http://www.energylabnordhavn.com/
[5] CITIES https://smart-cities-centre.org/
[6] https://smart-cities-centre.org/ 29 recommendations from the CITIES partners – direct link https://smart-cities-centre.org/wp-content/uploads/CITIES-Recommendations_april7_2021.pdf.
[7] Smart Cities Acellerator https://smartcitiesaccelerator.eu/

dem private rådgivningsfirma NIRAS med stærk repræsentation af industrielle partnere i styregruppen. Dette sikrede prioritering i at implementere forskningsresultater i kommercielle løsninger. Som vi vil se, begrænsede dette ikke forskningseffekten af HEAT 4.0, der også kan dokumentere en lang række forskningsresultater (se litteraturlisten i slutning af rapporten).

HEAT 4.0-projektet blev bevilget i februar 2019 af Innovationsfonden under programmet Grand Solutions med Journal nummer J.nr. 8090-00046B.

Den fulde titel er: HEAT 4.0 – Digitalt understøttet fjernvarme

NIRAS var ny som hovedansøger og projektleder til Innovationsfondens projekter under Grand Solutions investeringsprogrammet. I ansøgningsprocessen og undervejs i projektet blev den erfarne projektleder, Alfred Heller (med en stilling som lektor (Assoc. Prof.) på DTU og den tidligere rolle som Vicecenterleder i CITIES-projektet) derfor valgt som projektleder på projektet. Alfred Heller er også fungeret som leder tidligere og er medlem af talrige nationale og internationale forsknings- og innovationsprojekter. Ledelse og organisering af projektet er beskrevet i detaljer nedenfor.

Styregruppen, den autoritative organisation af projektet, er konsolideret af meget erfarne ledere af partnerorganisationen, og sikrede derved engagement til projektet på højeste niveau fra alle partnere, hvilket fint balancerede de kommercielle, innovative og videnskabelige interesser og ambitioner for projektet. Mere information om styregruppen og dens arbejde findes nedenfor.

Kommunikationen mellem partnerne foregik gennem et etableret SharePoint-websted og elektroniske mails. Hver måned blev der afholdt et såkaldt 'HEAT 4.0 Monthly', et møde til brug for videndeling mellem de forskellige partner aktører. I begyndelse af projektet blev disse møder ofte brugt til intern kommunikation og projekttilpasning, senere for at dele viden om konkrete løsninger, produkter, forskningsresultater of første salgssucceser. Alle disse Monthly-møder er blevet optaget og distribueret via det interne HEAT 4.0-websted. De bedste og mest informative møder findes i dag også på HEAT 4.0 hjemmesiden på https://heatman.dk/events/ under overskrifterne "HEAT 4.0 Monthly" møder.

Konkret arbejde og handlinger blev varetaget, organiseret i det vi kaldte 'Aktiviteter'. Indenfor disse anvendtes 'Workshops' og (online) møder til at koordinere arbejde på tværs af partnerorganisationer. Aktiviteter kunne inddrage forskellige partnere og samarbejdsformer, alt efter behov. Inddragelsen af ledelsen i disse aktiviteter var valgfrie og også mere dynamisk organiseret. I nogle tilfælde blev HEAT 4.0 ledelsen involveret for at få indsigt eller løse udfordringer. På denne måde opstod tværfaglige aktiviteter og indsamling/deling af viden, samt kommunikation blev lettet i det daglige arbejde.

Den aktuelle slutrapport opstiller HEAT 4.0-projektets resultater og efterlever forespørgslen på rapportering af HEAT 4.0 til Innovationsfonden under journalnummeret J.nr. 8090-00046B. Rapporten kan ud over fonden også være relevant læsning for øvrige i den private, offentlige sektor, innovatører og forskere. God læselyst og god læring.

Part I
About this HEAT 4.0 report

This report is an extended collection of information that may be relevant for anybody interested in the HEAT 4.0 project, described below. The report collects the main results from the whole HEAT 4.0 project. The content is arranged in a way where interested readers get an overview and hereafter go deeper into the details of a subject that are presented in later sections of the report. In this way, we aim at collecting as much evidence and experience as possible. Results can also be found on https://www.heatman.dk and mainly scientific results are listed at the partner project, CITIES, website https://smart-cities-centre.org. A literature list for the time of finalizing the current report can be found below. Updates will be published on the homepage by CITIES.

More detailed insights from the HEAT 4.0 project are presented in a number of dedicated reports and scientific publications. The relation between the different reports and synthesis of results are presented in Figure 1.

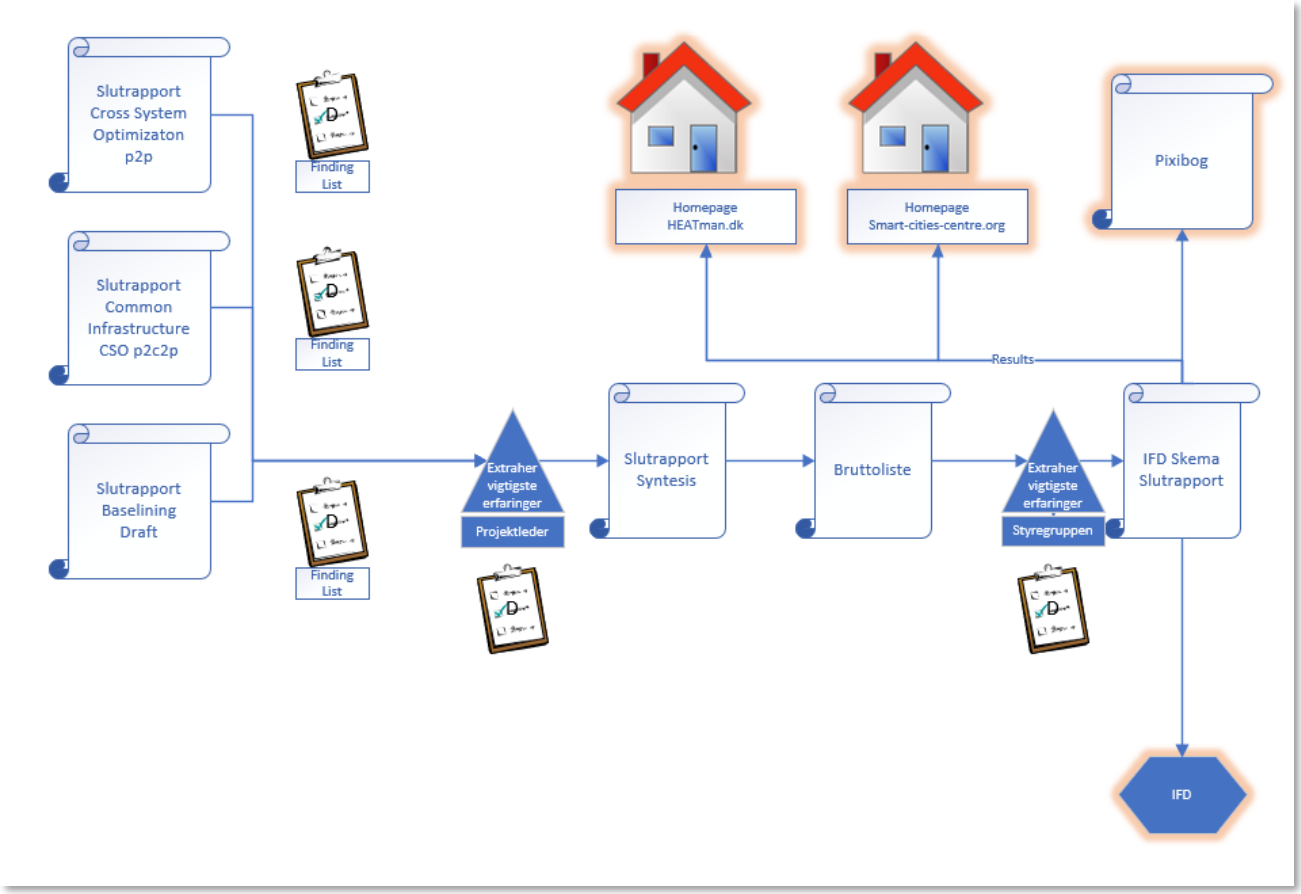


Figure 1: Document relations for final reporting in HEAT 4.0.

Figure 1 shows the final report in the centre of the chart (Danish: Slutrapport). It is a collection of different sub-reports aligned on the left side of the chart that makes up the results of HEAT 4.0 altogether:

1. An extended final report on the HEAT 4.0 project organization and results. (Current report).
2. Report on Cross System Optimization – peer to peer
3. Report on the Commercial Cloud and Common Infrastructure
4. Collection Report for Scientific Work in HEAT 4.0
5. Report on the findings in relation to the baseline methodology

On basis of the individual reports, a set of results is collected and analysed, resulting in an extract (synthesis) of results with high priorities. This list was presented to the Steering Committee from which they chose the most important achievements from the HEAT 4.0 project and reported finally to the Innovation Fund Denmark (IFD). You will find all these resources on the homepage https://heatman.dk.

3. Opsamling på dansk (Danish Summary)

Innovationsfondsprojektet 'HEAT 4.0 – Digitalt understøttet fjernvarme', J.nr. 8090-0046B under programmet 'Grand Solutions', blev udført efter planen fra 2019 til 2022 med et halvt års forlængelse. De tre aftalte nøgleevalueringskriterier opfyldes af konsortiets endelige løsning:

1) HEAT 4.0 'Cross System Optimization' fører til en besparelse i varmetab i netværket på mere end de aftalte 1-2%, hvilket Trefor casen kunne sandsynliggør[8] med de 2-3% besparelse [se nedenfor for detaljer.
2) HEAT 4.0-partnerne har implementeret endelige løsninger og værktøjer fra projektet hos de tre fjernvarmeværker i deres almindelige drift og på kommercielt basis.
3) HEAT 4.0 løsningerne er en kommerciel succes og implementeret i forskellige kombinationer hos over tre danske fjernvarmeværker, hvilket var målet.
4) HEAT 4.0-løsningerne er under planlægning for implementering på to serbiske fjernvarmeværker og er under forberedelse hos 1-2 estiske værker ledet af NIRAS som integrator. Danfoss har tilsvarende forhandlinger af end-to-end løsninger inkl. mulighed at integrere HEAT 4.0 koncepter som tilbydes i Nordamerika og Europa. Konceptet præsenteres i mange flere lande og blandt andet via IEA-samarbejdet om digitalisering af fjernvarme. IEA viste stor interesse for vores resultater, som ikke er tilsvarende succesfulde, andre steder.

Konsortiet har for alle partneres vedkommende forbedret det software og de IT-løsninger, som har været en del af HEAT 4.0, ved hjælp af forskningsbaserede banebrydende metoder. Projektet har dermed bidraget til et øget salg for de involverede virksomheder i Danmark og udlandet.

Den overordnede HEAT 4.0 holistiske serviceløsningstilgang og al anden innovation fra konsortiet, er testet og demonstreret hos tre varmeselskaber (Brønderslev Forsyning, Trefor og Hillerød Forsyning), suppleret med fjernvarme som ikke er medlemmer. De sidste har medført eksterne evalueringer fra disse værker. Overordnet består HEAT 4.0 løsningen af en 'fælles cloud-infrastruktur', der vil være kommercielt tilgængelig af partneren Center Denmark, og som erstatter forskningsinfrastrukturen 'Science Cloud'. Denne cloud løsning tilbyder håndtering af datadeling for fjernvarmeselskaber og softwareleverandører, ikke kun for HEAT 4.0, men snarere generisk, hvilket sikrer state-of-the-art sikkerhed, beskyttet privatliv og datakvalitet. Cloud-løsningen muliggør sammen med en standardisering af data-udvekslingsgrænseflader meget avancerede tjenester, som er demonstreret i den kommercielle løsning, kaldet Cross System Optimization (short CSO), der muliggør målrettet optimering på tværs af hele fjernvarmesystemet fra produktionen, til distribution og varmelevering til bygninger.

[8] Det er relevant at bemærke at et af resultater fra HEAT 4.0 projektet er, at egentlig bevisførelse eller videnskabelig dokumentation af dette 1-2%-krav ikke er mulig for et komplekst system som fjernvarmen og andre forsyninger. Dette fremgår af rapporten om 'Report on the findings in relation to the baseline methodology'.

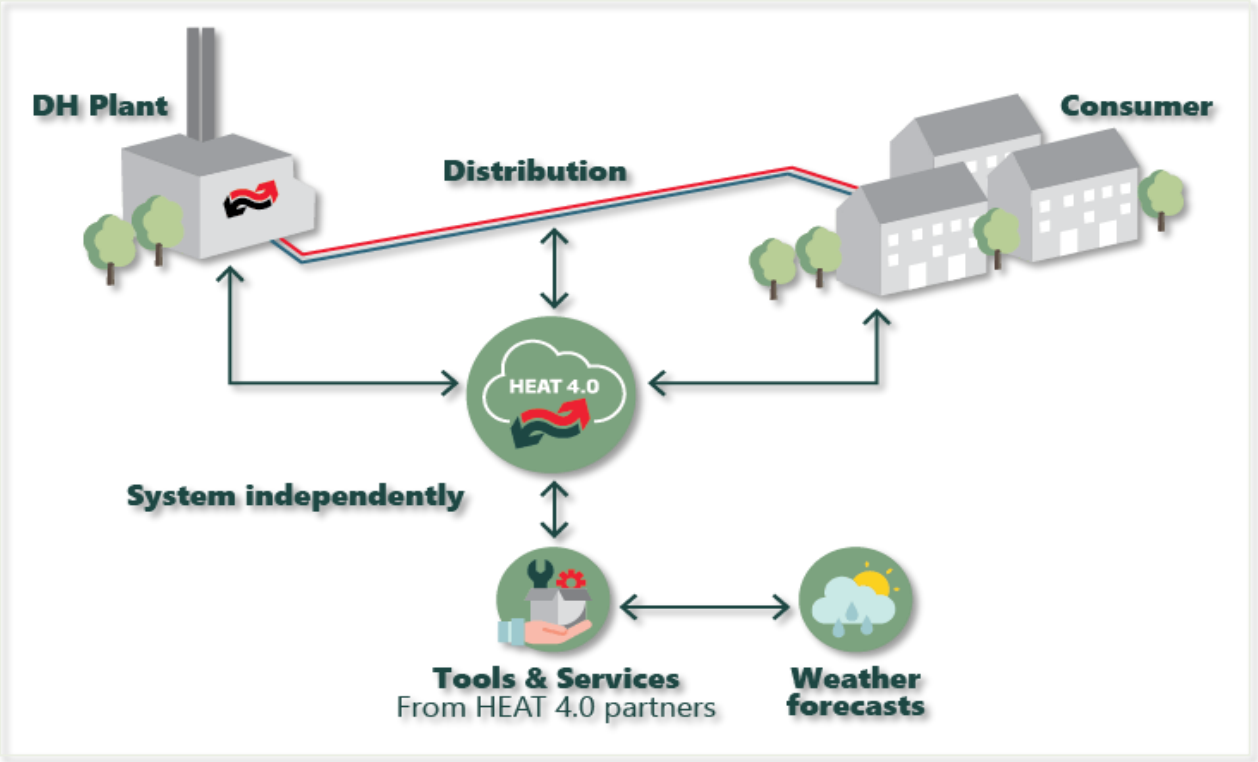


Figure 2: *Introduktion af standarder og en fælles datadelingsinfrastruktur (cloud) er nogle centrale komponenter i HEAT 4.0.*

De holistiske rammer kan eksemplificeres ved følgende innovative løsning inspireret af casen fra Brønderslev Forsyning, og som involverer alle partnere:

- Moderne bygninger styres af forskellige overvågnings- og kontrolsystemer, f.eks. af radiator- og gulvvarmetermostater i den mere simple ende samt fuldgyldige komplekse styresystemer med hundredvis af sensorer og avancerede styringsalgoritmer. De fleste bygninger bruger Smart Meters til at rapportere behov for varme, køling, vand, elektricitet og andre tjenester.
- Ovennævnte bygningsovervågningssystemer (BMS) producerer data, der kan bruges til mange formål, og til optimering af det omgivende servicenet (el, vand og varme), hvilket er formålet med HEAT 4.0. Igennem projektet er data blevet formidlet til relevante HEAT 4.0-partnere og kan i et fremtidigt konstellationer blive delt med andre åbne samarbejdspartnere, der kan foreslå besparelser og merværdier til fjernvarmeoperatører eller varmeforbrugere.
- I HEAT 4.0 kombineres data fra bygninger med data og viden fra selve fjernvarmenettet, bl.a. varme-/energiproduktionsenhederne, for at innovere holistiske tjenester, der tilfører værdi for forbrugerne af disse tjenester.
- En konkret demonstration af denne tilgang er Cross System Optimization, hvor uafhængige optimeringssystemer kombinerer deres indsigt i form af forudsigelser i form af data i en holistisk, tværsystem optimeringstjeneste. En sådan service kan have forskellige formål - f.eks. minimere fremløbstemperaturen for det samlede fjernvarmesystem, minimere omkostningerne til energiproduktion, tilbyde fleksibilitet til andre energinet (f.eks. elektrisk system) og så videre.
- En fjernvarmeoperatør kontakter en "Integrator", en partner i HEAT 4.0, for at få designet en tilpasset version af denne service til hans aktuelle situation og drift.

Forretningsmæssigt er løsninger der er udviklet i HEAT 4.0 regi, meget robuste på grund af de mange måder, hvormed de holistiske løsninger kan kombineres og tilpasses kundernes individuelle behov.

Ikke alle af projektets definerede mål er nået. Inddragelse af bygninger har været ekstremt krævende, og endnu mere vanskeliggjort af Covid-19-pandemien, der begrænsede vores adgang til bygningsejere og bygningernes installationer. Resultatet heraf var, at det kritiske antal bygninger, der kunne resultere i målbare besparelser i fjernvarmenettet, ikke blev opfyldt, og derfor er disse centrale evalueringskriterier blevet dokumenteret ved simulering, baseret på data fra fyringssæsonerne 2019 til 2022 (hvilket er én af grundene til at projektet blev forlænget med et halvt år)[9].

Også forventningen til at kunne indsamle data til en 'baseline' og dokumentere kvantitative og målbare resultater ved et projekt som HEAT 4.0, har vist sig forkert på grund af de mange forhold, der påvirker et så komplekst system som en fjernvarme. Dette vigtige indsigt er rapporteret af Dansk Fjernvarmeforening[10] og er et internationalt anerkendt resultat (IEA-samarbejde).

HEAT 4.0-konsortiet har udviklet og demonstreret adskillige digitalt understøttede løsninger til mange aspekter af fjernvarmesektoren, der viser den generiske anvendelighed af de overordnede koncepter og løsninger. Blandt disse kan vi nævne:

- Data fra fjernvarmesystemet og fra dens kunder danner grundlaget for de digitale tjenester. Derfor har forskningen fokuseret på datadrevne metoder for mange af de involverede softwareløsninger til forudsigelser, optimering og kontrol på tværs af fjernvarmesystemet.
- Standardiseret og kvalitetssikret datadeling.
- Anvendelsen af Smart Meters åbnede for nogle af de innovative løsninger, der blev udviklet, blandt andet en løsning, der anvender repræsentative målere som erstatning af fysiske målinger i nettet som er meget dyre at etablere og som kan være placeret forkert i net der med tiden er blevet forandret.
- HEAT 4.0 forbedrede lokale vejrudsigter, tilbudt af Enfor ved brug af DTU Computes teoretiske metoder, baseret på data fra Smart Meters.
- HEAT 4.0 forbedrede investerings- og varmeproduktionsplanlægning, tilbudt af Enfor ved brug af DTU Computes teoretiske metoder.
- Forbedrede modelleringsevner for partnere.
- DESMI har udviklet en testrig teknologi, der kan anvendes til enhver stor pumpe, hvilket muliggør test og optimering (en del af CSO'en) af pumper. Testrig er en ny og innovativ funktion tilbudt af DESMI og de opsamlede data er anvendelig til modellering af de aktuelle pumper, også fra konkurrerende leverandører. Ved at anvende IoT sensorer som deler deres data over Internettet, sammen med de resulterende modeller fra testningen, er det muligt at tilbyde 'Predictive Maintenance' for pumper over hele verden.
- Logstor, nu opkøbt af Kingspan: Virksomheden forventede emnet 'lækagedetektion' som hovedfokus ved projektstart, bakket op af bl.a. NIRAS. Emnet blev nedprioriteret på grund af manglende ressourcer. Fokus for Logstor blev derfor ændret til at innovere og udvikle værktøjer til planlægning og investering i fjernvarmenet med hensyn til nettes livslange økonomiske indikatorer, CO2-regnskab og økonomisk CAPEX og OPEX. Dette værktøj er allerede blevet bredt udbredt på det internationale marked.
- Danfoss forbedrede styringen af deres varmeunits, som er overgangen fra fjernvarme til bygninger og dermed dokumenterede besparelser på varmtvandssystemer med deres udstyr. Kombinationen med Leanheat-technologien har yderligere skubbet i denne retning.

[9] Andre årsager er at de involverede PhD hverken kunne nå at indsamle data eller gennemføre deres studie i den korte projektforløb.
[10] Denne indsigt er forsøgt opsamlet af Danske Fjernvarme i 'Report on the findings in relation to the baseline methodology'.

- Danfoss Leanheat, som det hedder nu, har naturligvis havde en stor indflydelse på HEAT 4.0 gennem deres erfaringer med end-to-end løsninger som blandt meget andet kan levere systemer og komponenter til en CSO m./u. HEAT 4.0 komponenter efter behov fra kunderne.
- HEAT 4.0 har haft en afgørende betydning for fjernvarmesektorens digitaliseringsdagsorden, som Dansk Fjernvarmeforening har dokumenteret.
- Forskningen inden for HEAT 4.0 har været massiv og har resulteret i mere end 100 publikationer i videnskabelige tidsskrifter, bogbidrag, konferencepræsentationer og faglige publikationer (se listerne i slutningen af rapporten).
- De nævnte punkter viser tydeligt at HEAT 4.0 har medført ændringer i virksomhedens forretningsmodeller og tilbud hvilket har medført væsentligt og forbedre internationale konkurrenceevne for disse virksomheder.

Detaljer for enkelte af de refererede resultater findes beskrevet nedenunder. Videnskabelige resultater er samlet i 'Collection Report for Scientific Work in HEAT 4.0'. Detaljer findes i de videnskabelige publikationer som er opført i listerne i slutning af nærværende rapport og på projektets hjemmeside samt CITIES hjemmeside. Yderligere informationer kan indhentes hos de enkelte HEAT 4.0 partnerne, som fremgår af Figure 3.

Fremtidige videreudvikling af HEAT 4.0-konceptet vil blive besluttet i efteråret 2022, og kommercielle tilbud herpå er i gang. Endelige kontrakter forventes i løbet af 2022.

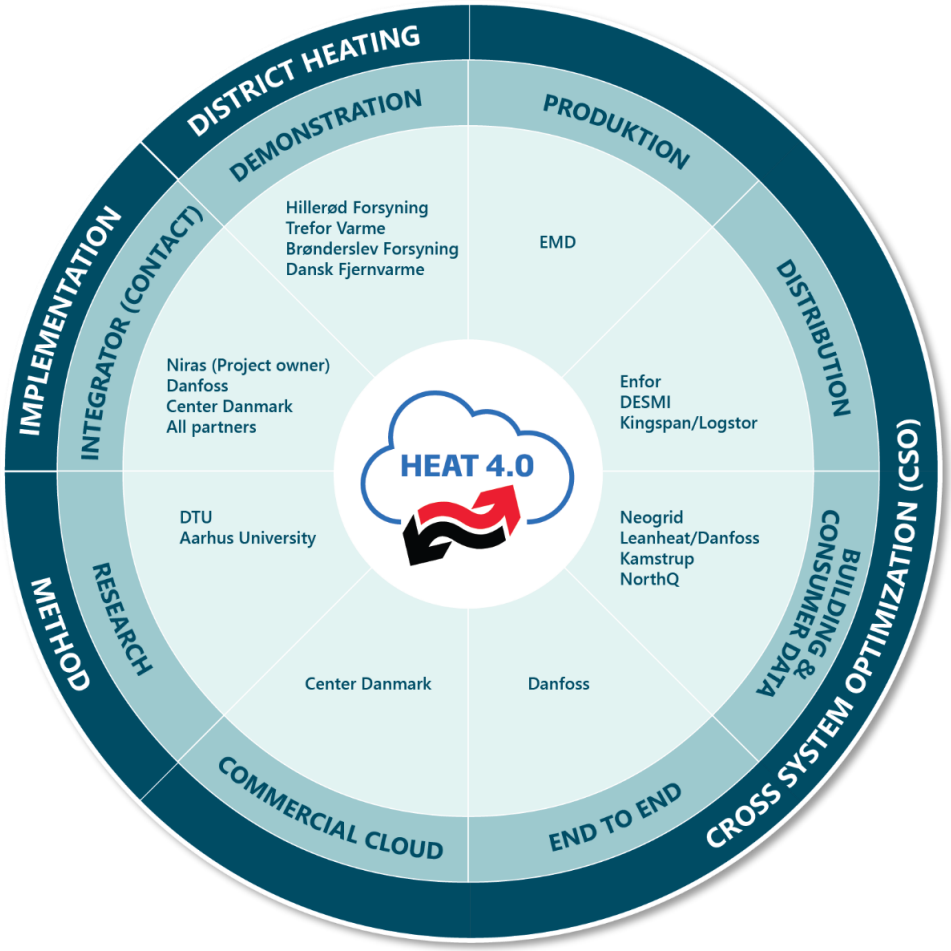


Figure 3: HEAT 4.0 partner og deres bidrag og roller i konsortiet.

4. English summary

The innovation project 'HEAT 4.0 – Digitally supported District Heating' with Journal number 8090-0046B by the Innovation Fund Denmark is supported under the program 'Grand Solutions'. The project is carried out according to the plan - from 2019 to 2022 with a half years prolongation. The three agreed key evaluation criteria are met by the consortium's final solution:

1) The HEAT 4.0 Cross System Optimization leads to a savings in heat loss in the network of more than the agreed 1-2%. The Trefor case shows 2-3% of saving [see below for details].
2) The HEAT 4.0 Partners have implemented final solutions and tools from the project in their daily operation and will keep them under commercial conditions for future use.
3) The HEAT 4.0 solutions are a commercial success and implemented in various combinations at three Danish district heating systems.
4) The HEAT 4.0 solutions, involving several partner organisations, is under planning at two Serbian district heating plants and 1-2 Estonian district heating plants, headed by NIRAS and at several district heating plants in Europe and Nord America headed by Danfoss through the 'end-to-end' solution. The concept is presented in many more countries, and through the IEA cooperation focusing on the digitalisation of district heating. This cooperation showed high interest in our achievements that are not seen similar successful other places.

Above these evaluation criteria, the HEAT 4.0 consortium improved all involved software and IT-solutions for all partners by research-based cutting-edge methodologies and hereby contributed to increased sales for the involved companies in Denmark and abroad.

The overall HEAT 4.0 holistic service solution approach and all other innovations done by the consortium, are demonstrated at three member partners (Brønderslev Forsyning, Trefor and Hillerød Forsyning), supplemented by some non-member district heating companies, which has enabled an external evaluation. One solution consists of a 'common cloud infrastructure' that will be commercially available by the partner Center Denmark until then the solution is provided by the research infrastructure 'Science Cloud', provided by DTU as a research and educational resource. The cloud offers the handling of data sharing between the district heating and software solutions, not only for HEAT 4.0 but rather generic, ensuring state-of-art security, protection of privacy and data quality. Also, this cloud solution, together with a standardization of data-exchange interfaces, enables very advanced services that are demonstrated in the commercial solution, called Cross System Optimization (CSO). It enables the multi-target optimization across the whole district heating system from the production, to the distribution to the heat delivery to the end-user, e.g. buildings.

The holistic framework is exemplified by the following innovative solution inspired by the case at Brønderslev Forsyning, involving all partners:

- Modern buildings are controlled by various monitoring and control systems – this could be radiator- and floor heating thermostats on the simple end of the spectrum, and full-fledged control systems with hundreds of sensors and advanced control algorithms on the other end of the spectrum. Most buildings use smart meters to report demands for heating, cooling, water, electricity and other network services.
- The above-mentioned building monitoring systems (BMS) produce data that can be utilized for many purposes, amounts these for the optimization of the surrounding energy networks, which is exactly the purpose for HEAT 4.0. The data is communicated to relevant HEAT 4.0 partners and will in a future setup be shared openly with other business partners that can propose added values to the district heating operators or heat consumers.

- In HEAT 4.0, the data from buildings is combined with data and knowledge from the district heating network itself and with the heat/energy production utility to innovate holistic services that add value to the consumers of these services.
- A concrete demonstration of this approach is the Cross System Optimization service where independent optimization systems combine their insights in form of predictions through data in a holistic, optimization service. Such a service may target different objectives, e.g. minimizing supply temperature for the overall district heating system, minimizing the cost for energy production, offering flexibility to other energy networks (e.g. electrical system) and so on. The district heating operator contacts a single point-of-contact, called a 'HEAT 4.0 Integrator', to design and adjusted version of this service for the current situation at the individual plant in question.

Business-wise, HEAT 4.0 has proven very robust due to the many ways holistic solutions can be combined and adapted to the needs of the customers.

Not all predefined targets have been met by the HEAT 4.0 consortium. The recruiting of buildings has been extremely demanding and increasingly difficult due to the Covid-19 pandemic which has limited access to these building owners and hereby the building installations. The result hereof was, that the critical number of buildings that would result in measurable savings in the district heating network, was not met and hence this key evaluation criteria has been documented by simulation based on data from the heating seasons 2019 to 2022 (which was one of the reasons to prolong the project by half a year[11]).

Also, the idea of being able to collect data for a 'baseline' and document quantitative and measurable results has been shown wrong because of the many circumstances that impact a complex energy system such as district heating. This important discovery has been reported by the Danish District Heating Association and communicated to the IEA DHC Annex TS4 on the digitalization of district heating.

The HEAT 4.0 consortium has developed and demonstrated numerous digitally-supported solutions for many aspects of the district heating sector that show the generic applicability of the overall concepts and solutions. Amongst these we can mention:

- Data from the district heating system and the heating customers form the basis of digital services. Hence, research has strongly focused on data-driven methodologies for many of the involved software solutions for predictions, optimization and control across the district heating system.
- Standardized and quality-assured data sharing.
- The utilization of 'smart meters' did open for more innovative solutions that were developed to market-ready solutions, amongst these a solution that applies representative meters to represent a given subnet that can replace very expensive measurements, which were necessary in earlier solutions. This approach is very flexible and can be applied to many other applications.
- HEAT 4.0 improved local weather forecasts, offered by Enfor by the use of theoretical methodologies of DTU Compute.
- HEAT 4.0 improved investment and heat production planning, offered by EMD by the use of theoretical methodologies of DTU Compute.
- Improved modelling abilities for partners.
- DESMI has developed a test rig that can be applied to any large pump on the market and hereby contribute to the testing of pumps. The data from these tests were applied for the development of models for given pumps (machine learning methodologies). Informed by IoT sensors that were

[11] Other reasons where that the involved PhD did not have the time to finalize their analysis and study within the project.

also developed in HEAT 4.0 these models are now applied for 'Predictive Maintenance' on a worldwide market for district heating pumps, but also maritime and food-tech applications.

- Logstor, now acquired by Kingspan: The company expected to work on the topic 'leakage detection' as their main focus, but this was not addressed during the project due to lack of resources. They therefore changed the focus to innovate and develop tools for the planning and investment of networks and their life-long economic indicators, both CAPEX and OPEX. This tool has already been widely adopted in the international market.
- Danfoss improved the savings from their hot water systems.
- HEAT 4.0 has had a decisive impact on the digitalization agenda of the district heating sector, as documented by the Danish District Heating Association.
- Research within HEAT 4.0 has be very wide spread and did result in 100+ publications in scientific journals, book contributions, conference presentations and professional publications.
- The above solutions have affected or even changed the business model of the companies decisively and improved the organisation's international competitiveness accordingly.

Details for some of the referenced results are described below. Scientific results are collected in the 'Collection Report for Scientific Work in HEAT 4.0'. Details can be found in the scientific publications listed at the end of this report, on the project's website and the CITIES website. Further information can be obtained from the individual HEAT 4.0 partners, as shown in Figure 4.

Future further development of the HEAT 4.0 concept will be decided in autumn 2022, and commercial offers for this are underway. Final contracts are expected during 2022.

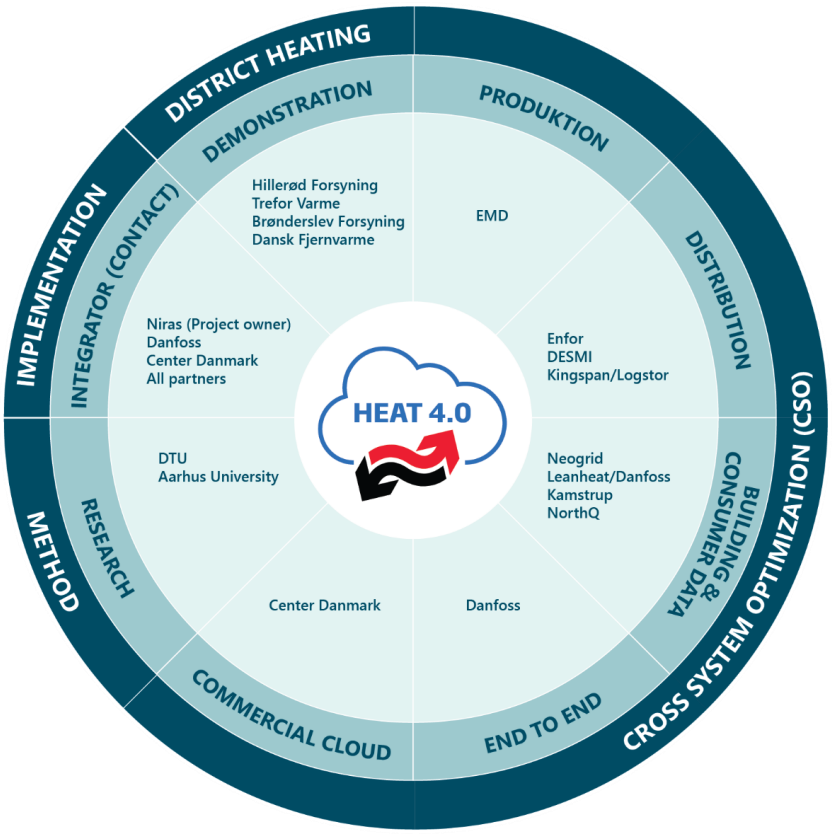


Figure 4: HEAT 4.0 partners and their contribution or role in the HEAT 4.0 consortium.

Abbreviation and terminology

CC	Commercial Cloud, and Common Cloud
CCI	Common Cloud Infrastructure
CS	Cross System - a basic concept applied in the HEAT 4.0 project
CSS	Cross System Service In two 'dimension': • the (special) system component dimension (production, network and buildings) • the temporal dimension (operation, short-term and long-term planning) Sub-system of the energy system (waste heat from industries, energy exchange between the electrical grid, transport etc.)
CSO	Cross System Optimisation - a CSS aiming at optimizing across the DH system. PS: Various implementations and dimension can be optimized.
DH	District Heating
DHC	District Heating and Cooling
HEAT 4.0	The consortium, organisational and technical platform behind HEAT 4.0 The current innovation project, supported by the Innovation Fund Denmark, J.nr. 8090-00046B
HEATman	Products for district heating, implementing the HEAT 4.0 solutions under this brand by NIRAS. PS: NIRAS applies this naming principle, 'man' for 'management', also for other utilities solutions, LEAKman for the water sector, DRAINman for the return water systems etc.
IFD	Innovation Fund Denmark
KPI	Key Performance Indicator
P2P or p2p	Peer to peer – direct communication between individual digital solutions
P2C2P or p2c2p	Peer to common, or peer to cloud – communication from the individual digital solutions to the cloud or common infrastructure. The peers do not directly communicate as in the p2p implementation.

5. Introduction

The current document aims at:

Primarily	reporting to the Innovation Fund Denmark with respect to the Grand Solutions project with Journal number 8090-00046B.
Secondarily	supporting different readers and communities from industries, consulting, innovation, business and science. Hence extended literature and a result review can be expected from the readers.
Thirdly	supporting authors of written content and communication to have a background document for their work to pick from or reference to (if published).

5.1 About the genesis of HEAT 4.0 – Digitally supported District Heating

The chosen partners were selected to bridge across the whole district heating sector and innovation cycles. Hence, both big organizations and small start-ups, industries, interest organizations and companies in consulting, innovation and research institutes are involved. Three case district heating companies joint the proposal at partners at the time of application and others joint as application cases later, also due to an project KPIs described later.

The partners in HEAT 4.0 are listed according to the numbering applied in the reporting to the Innovation Fund Denmark.

P1	NIRAS (Project leader)
P2	Aarhus University, Building Department
P3	Technical University of Denmark, Dept. of Computing
P4	Technical University of Denmark, Dept. of Management
P5	Technical University of Denmark, Dept. of Building Science
P6	Danfoss A/S – Heating Department
P7	Leanheat Oy (owned since 2020 by Danfoss)
P8	EMD International A/S
P9	ENFOR A/S
P10	Neogrid Technologies ApS
P11	Trefor Varme A/S (district heating operator)
P12	Kamstrup A/S

P13	Danish District Heating Association and Groen Energi
P14	Tmrow (exited the project early)
P15	Brønderslev Forsyning (district heating operator)
P16	LOGSTOR A/S (owned since 2021 by Kingspan, UK)
P17	Hillerød Varme (district heating operator)
P18	NorthQ
P19	Unnamed – Undistributed budget at time of application
P20	DESMI
P21	Center Denmark (since 2021)

Table 1: HEAT 4.0 partner organisation.

5.2 Organisation of HEAT 4.0

The project management was executed in cooperation between the *authoritative Steering Committee* and NIRAS with Alfred Heller as the *project leader*.

The steering committee, as the formal authority of HEAT 4.0, was appointed with one representative from each partner organization. Not all organizations wished to be an active part of the committee. Hence the resulting list of members (with comments on changes) during the projects lifetime:

No	Organisation	Representative	Role (years)
P1	NIRAS	Michael Lassen Schmidt Stefan Schmidt	from 2020 chairman until 2020
P2	Aarhus University Building Department	Steffen Petersen Søren Wandahl	from 2020 until 2020
P3	Technical University of Denmark Dept. of Computing	Henrik Madsen	
P4	Technical University of Denmark Dept. of Management	Represented by P2	
P5	Technical University of Denmark Dept. of Building Science	Represented by P2	
P6	Danfoss A/S – Heating Department	Atli Benonysson (Vice chairman)	

P7	Leanheat Oy (owned since 2020 by Danfoss)	Represented by P6	
P8	EMD International A/S	Anders Andersen	
P9	ENFOR A/S	Represented by P8	
P10	Neogrid Technologies ApS	Represented by P8	
P11	Trefor Varme A/S	Helge Hansen	chairman since 2020
P12	Kamstrup A/S	Represented by P16	
P13	Danish District Heating Association and Groen Energi	Kim Behnke	
P14	Tmrow (exited the project early)	N/A due to early exit caused by move of the company to France	
P15	Brønderslev Forsyning	Thorkil Bartholdy Neergaard	
P16	LOGSTOR A/S (owned since 2021 by Kingspan, UK)	Martin Lindgaard Pedersen	
P17	Hillerød Varme	Represented by P15	
P18	NorthQ	Represented by P8 and P16	
P19	Unnamed Undistributed budget at time of application	N/A – administrative pseudo partner, collecting non-distributed fundings	
P20	DESMI	Represented by P8 and P16	
P21	Center Denmark (since 2021)	Søren Skov Bording	from 2021

Table 2: Steering Committee members, roles and organisation.

The Steering Committee did meet physically at different locations, 4 times a year for a 3-5 hours meeting. Minutes and agendas are archived on the common SharePoint site at NIRAS. During the Corona period (2020-2022), the meetings were held on digital platforms, Teams and Zoom.

Daily management and leadership was conducted by NIRAS with the following actors:

Alfred Heller[12]	Project leader Contact person to Steering Committee Contact to Innovation Fund Administration Daily operation
Susanne Aagaard Madsen	Financial management
Eva Lange Rasmussen	Communication work, package lead
Michael Lassen Schmidt	Internal project director, contact to investment manager in IFD
NIRAS	SharePoint website for project management
NIRAS	Homepage, heatman.dk
DTU Compute	CITIES homepage for scientific dissemination
NIRAS	Standard financial system applied for project management

Partner communication was mainly driven by email, supported by a SharePoint website[13]. Every month a so-called HEAT 4.0 Monthly was applied for knowledge sharing. At the beginning of the project the meetings were often used for internal communication and project alignment, later to share findings, products, results and others between partners and their involved personnel. All these sharing sessions were recorded and distributed through the internal SharePoint website. Especially informative sessions are also shared on the homepage, heatman.dk.

Workshops and meetings were a good way of working across partner companies and organizations. Activities could consist of various partner combinations and change dynamically, according to demands. If the involvement was relevant, or cross activity and cross work package communication were helpful, necessary (online) meetings were facilitated in the daily work.

The implementation of activities was arranged by the partners internally with minimal intervention by the project leader.

[12] , with a background as a Vice-Center leader in the CITIES project and project researcher at the Energy Lab Nordhavn and many more research and innovation projects, in the role of Assoc. Prof. at DTU Civil Engineering and before

[13] https://NIRAS.sharepoint.com/sites/10403518EX

5.3 Success Criteria for HEAT 4.0

With the grant award from the Innovation Fund Denmark (IFD), of 25 Mio. Danish Kroner (DKK), equals approx. 3.3 Mio. €, a set of success criteria was negotiated, ending in the following few Key Performance Indicators (KPI). The texts are directly taken from the agreement text and translated from Danish. Local notes are given to ensure a better understanding.

KPI 1: HEAT LOSSES IN THE PIPE NETWORK
Achieved energy savings in the heating network of 1-2% in comparison with the heating season, which runs from October 2019 to April 2020 at the district heating plants involved.

KPI 2: BUSINESS VALUES
The HEATman concept means that all 3 DH companies that are partners in the project have implemented all or parts of the concept, also after the project.
In addition, at least 3 Danish district heating plants have installed a minimum of 2 tools from the HEATman platform on their plants, and at least one foreign district heating plant has implemented parts of the concept.

Local notes [from the application]:

1) Energy savings in the district heating are calculated according to the method published in "Turnkey: Calculation of the heat loss in the pipe network after performing temperature optimization" or H. Madsen, O.P. Palsson, K. Sejling, H.T. Søgaard: Models and Methods for Optimization of District Heating Systems; Part II: Models and Control Methods, IMSOR, DTU, 208 pages, 1992 (EFP89-14 Final Report) and **(Madsen et al., 1992)**. In HEAT 4.0, the District Heating Association and Grøn Energi developed further on these approaches and this approach is presented below.

2) The term HEATman and HEAT 4.0 were synonyms of the 'same' at the beginning of the project. The steering committee decides in 2020, that the project name 'HEAT 4.0' was the name to be applied by all partners and resulting products, whereas the term 'HEATman' is a NIRAS product name that is owned by NIRAS A/S and hence, not handled by the partnership.

The above KPIs can be explicitly stated as:

1) Energy losses in the district heating networks are reduced by 1-2% compared to the last year of operation before the entering of HEAT 4.0 (winter season 2019-2020).
2) All three DH partners are applying products from HEAT 4.0, also after the ending of the HEAT 4.0 project.
3) At least 3 Danish district heating, not being partners, are applying at least 2 or more products from the HEAT 4.0 project.
4) At least 1 international (non-Danish) district heating has implemented parts of the HEAT 4.0 concept.

These KPIs were the main drivers for the work to be done, but additional goals were added during the project execution, called internal goals.

Internal HEAT 4.0 goals:

- Added value is pivotal for the district heating partners. It is this goal that has based the reasoning for the HEAT 4.0 project. It was also this driver that motivated the choice of the concept of 'commercial cloud' which is also called 'common infrastructure component'. Another motivation factor of the DH operators is called 'plug n'play', which means that the solutions applied can be replaced by others with minimal effort.
- The value issue was of most importance for all commercial partners and hence the Business modelling was pivotal. It was this driver that turned research-to-commerce into research-support-commerce.
- Communication with the district heating sector was pivotal for the Danish District Heating Association, represented by 'Grøn Energi' as a partner and the project leader NIRAS.
- Research outputs were the main goals for universities in addition to the more commercial and project-related goals.

Please find the reported results in Danish and English in the Summary section above, and the Result section below.

5.4 Results regarding KPI

Ad KPI 1) Reduced heat losses in the district heating network could not be directly measured as assumed by the concept of 'baseline'. Hence simulations in the program TERMIS are applied with the inclusion of data from the measurement for the involved periods. The results of these simulations document a reduction of the heat loss in the district heating net due HEAT 4.0 (and any other change to the system) by 2-3% over the project period, which is more than expected (1-2%). The computations are carried out for Trefor and Brønderslev, while a change in staff made this effort impossible for the Hillerød case.

Ad KPI 2 and 3) All three partners - district heating companies, Brønderslev Forsyning, Trefor and Hillerød Forsyning, did adopt the solutions by HEAT 4.0. Every partner chose the solutions that met their demands, e.g. Trefor adopted the data-sharing cloud infrastructure, which at the current time is the Science Cloud, but will change to the Commercial Cloud at the end of 2022. Hereby, communication from the plant goes through this common component to all the involved software. Trefor tested the solutions on one subnet and implemented the solution on all 15 subnets in 2022. Brønderslev Forsyning adopted almost any of the possible aspects in HEAT 4.0, tested the solutions on one subnet and implemented them on all 3 subnets in 2022. Hillerød Forsyning did adopt the control components for all their subnets in 2021 after testing on one subnet.

Ad KPI 4) Parts of the HEAT 4.0 concept are applied by Leanheat in Finland, being the origin of the company. There are negotiations on applying HEAT 4.0 concepts with the energy company Tartu in Estonia, where physical improvements on the district heating system have been prioritized above digital improvements. However, the plans are to implement HEATman concepts by NIRAS during the coming years. Currently, workshops are held in Serbia with two district heating plants, a large one and a small one, where the HEATman application is ongoing. Danfoss driver several negotiations in both Europe and Nord America.

The internal goals are widely met, where the commercial cloud delivers a kind of 'plug'n play' solution that reduces the demand for specialized IT skills at the DH companies. The Danish District Heating organization is currently collecting pieces of evidence regarding digitalization in the sector and is hereby able to correlate the demand for HEAT 4.0 solutions. The universities did deliver solutions directly into commercial solutions as reported in the final report on CSO p2p (See literature list below). Assens Fjernvarme and Sindal Fjernvarme are the first commercial setups, where the three partners Kamstrup, Enfor and EMD did deliver a HEAT 4.0 concept for optimizing their networks and

production capacity with inputs directly from smart meters. Other projects are driven by Center Denmark which builds a solution where HEAT 4.0 concepts are merged into solutions from other IFD projects (e.g. FED). The above-referenced international business case is handled by NIRAS under the label HEATman, where NIRAS acts as an Integrator of HEAT 4.0 components (concept by HEAT 4.0), as a single point of contact. This will probably be the most applied future international business case by the HEAT 4.0 consortium. This business model is supplemented by Danfoss in a different configuration of involved tools, software and solution from Danfoss and other partner contributions.

5.5 Operational aspects

As mentioned earlier, knowledge sharing was done on a SharePoint site that consisted of a NIRAS internal part and an external partner part. The internal part was used for NIRAS for internal and administration aspects, whereas the external part was applied for partner information. The project has a homepage on https://www.heatman.dk and a collection of important information, recordings from presentations, publications and more can also be found on the homepage of the CITIES-project at https://smart-cities-centre.org/. In this way, the sharing of the results is also ensured after the ending of the HEAT 4.0 project.

Another source for knowledge sharing was the "Monthly meetings", where internal information sharing was facilitated. Recordings from the meetings are collected on SharePoint for the project. A subset of informative recordings is shared also on the homepage of HEAT 4.0.

A name list of active individuals was maintained by the project lead, collecting all active persons involved in HEAT 4.0. This list was applied to general correspondence, invitations to common tasks and events and knowledge sharing. The list consists of 100+ individuals plus another 30+ individuals, that have left the project during the project phase. The list collects the actors within the individual organizations, Masters students and PhD, visiting researchers and many more persons that were involved, which are not counted.

The HEAT 4.0 project was originally organized in work packages, which showed to be not very operational from the beginning because much innovation could not be arranged in this way. Hence, more dedicated and operational Activities were defined and applied in the daily management of the project. The list of activities was adjusted, as experiences were collected. Some activities were merged and others dropped due to different reasons. This current reporting reflects the operational decisions that the reader will find below. A survey on activities is listed in Table 3. Activities that were not developed due to an irrelevant maturity, are greyed out.

Table 3 Target Activities for innovation efforts in HEAT 4.0. Greyed out lines are not brought to a final solution stage.

A1	Adjustments at the DH infrastructure	
A2	Common infrastructure components and methods	
A3	Data intelligent research based solutions	
A4	DH industries components integration	
A5	Improved forecasting	
A6	CO2 monitoring, control, visualization and reporting	
A7	N/A	

A8	Electrification, Sector coupling, Renewable Energy Source integration	
A9	Smart buildings	
A10	Leakage detection	
A11	Short term planning	
A12	Long term planning	
A13	Baseline, screening tools	
A14	Value identification and business models	
A15	Export – opportunities and efforts	

Above mentioned activities were run individually and in parallel with necessary coordination and cooperation across activities carried often out by the project lead and were mostly ensured through the common SharePoint infrastructure and the Monthly meetings described earlier.

5.5.1 Changes in organizational responsibilities

During the project, different changes in responsibilities concerning target activities were necessary:

A6 - where Tomorrow was responsible - was stalled because the company moved from Denmark to France, with the consequence that they did not prioritize the heating sector in their CO2 modelling and services.

A3 and A4 - were closely related and let by DTU Compute at the time of application. Due to the maternity leave of the responsible staff, the two activities were split and Enfor got the responsibility to implement the "Cross System Optimization", while DTU Compute kept the responsibilities for the data intelligent-modelling, forecasts and solutions. This led to adjustments of the definition of the CSO to be implemented as Peer-to-Peer (p2p). The subject will be presented in depth below.

A2 - the Science Cloud was moved to Center Denmark. Center Denmark joined the project as an additional partner in the second half of the project period. The commercial part of the cloud infrastructure was 2021 moved from NorthQ to Center Denmark. The innovative solutions that enable district heating companies to control access to their data on the Commercial Cloud was an innovation that was implemented by NorthQ, together with a data model and storage. Unfortunately, these components did not meet the principles applied by Center Denmark that had to re-code them in their environment. DTU Management, which is responsible for the research cloud infrastructure, Science Cloud for CITIES, is maintaining this infrastructure component that is now hosted by Center Denmark activities.

5.6 Communication to the DH sector, industries and public

The communication within HEAT 4.0 and dissemination to the surroundings, was placed in a dedicated work package. At the beginning of the project, a communication strategy was made and a communication group with partner representatives was built. These resources were not activated due to a lack of relevant results to be presented to a wider public.

At the end of the project, during 2022, the external communication was accelerated dramatically, which made sense, having results to present at this later stage of the project. The easiest way to get an overview of these activities, you find information on the HEAT 4.0 homepage heatman.dk and the scientific parts on the CITIES homepage.

Part II

Results and Achievements

As the reader will notice, there are numerous achievements developed by HEAT 4.0. To give the various readers a chance to find the relevant results, we split the collection of achievements into sections that reflect the various target groups.

Target groups:

1) The Clients – District Heating Operators
2) The Client Association (District Heating Sector)
3) The commercial partners, software developers and component industries
4) Science

6. Achievements for the DH Operators – A self-evaluation

In this section, the achievements, results and evaluations by the district heating operators are collected and explained. We have three DH partners in the HEAT 4.0 consortium, Brønderslev Forsyning, Trefor and Hillerød Forsyning. Current, the former two have contributed to this report, whereas the latter is pending. These partners, like the other partners, have made a presentation of themselves in the 2-pagers - placed on the homepage www.heatman.dk and the CITIES homepage.

6.1 The three district heating partner

The three district heating companies are probably the best to judge the HEAT 4.0 project in the most appropriate way, because of being the customers to buy the products and services from the project business partners.

6.1.1 Common findings for the three DH partners

To utilize huge systems/cases such as district heating in innovation and scientific research, showed to be a very demanding task. Also, preconditions such as IT skills were not in place and had to be adjusted and communication between partners had to be established. All these affected the plans and led to delays at the early stages of the project.

When entering the HEAT 4.0 project, all communication from district heating systems was made individually to each involved software provider. In other words, for every software supporting the DH operation, there had to be found a communication solution that met the demand of both sides. The result was an IT-architecture, as shown in Figure 5, that could not be efficiently maintained. HEAT 4.0 addressed this challenge.

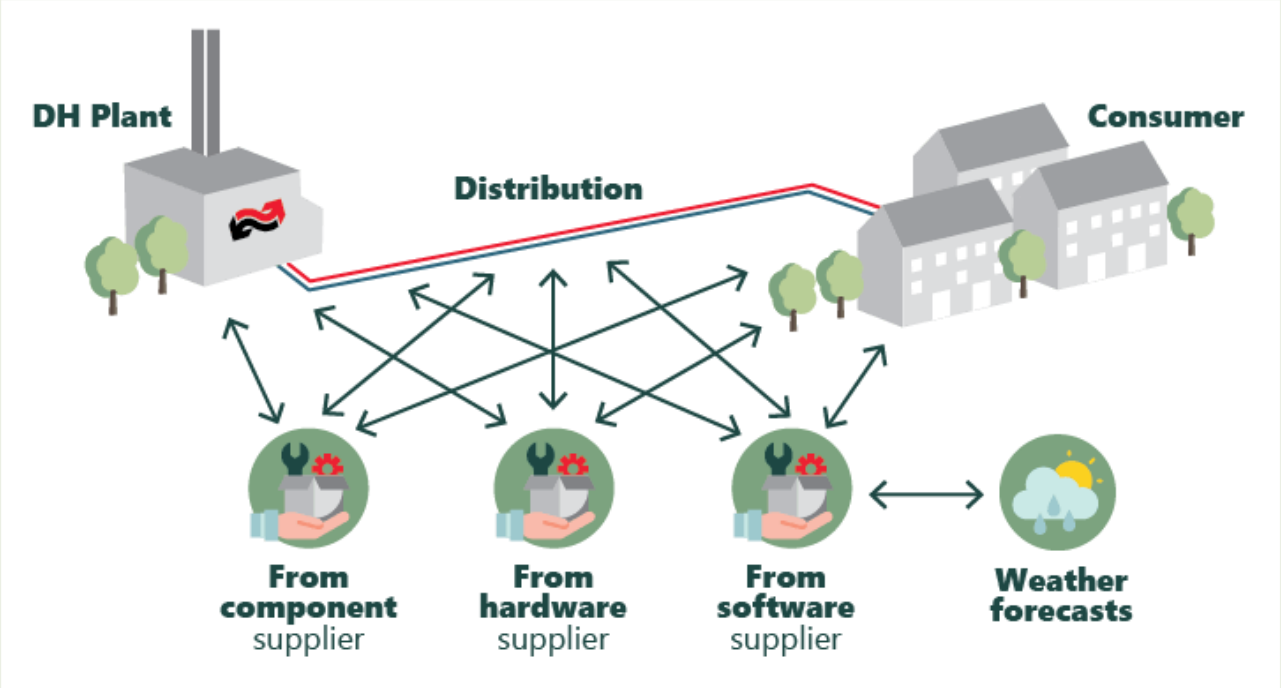


Figure 5: Implementation of communication for individual software packages end in a digital 'spaghetti' architecture.

The first step in the preparation of district heating infrastructures for HEAT 4.0 is to adopt standardized of such interfaces. The Industry 4.0 standard OPC-UA, which gave HEAT 4.0 its name, was proposed as the most prioritized standard. This standard is applied in the communication between the district heating system and its surroundings, e.g.

sharing data with software solution providers. It can be mentioned already here, that REST-API is the standard recommended between software partners and also the Common Cloud infrastructure, involved later.

The second step to enable district heating infrastructures to be able to utilize holistic HEAT 4.0 solutions was the proposal of a common platform for the handling of data as shown in Figure 6.

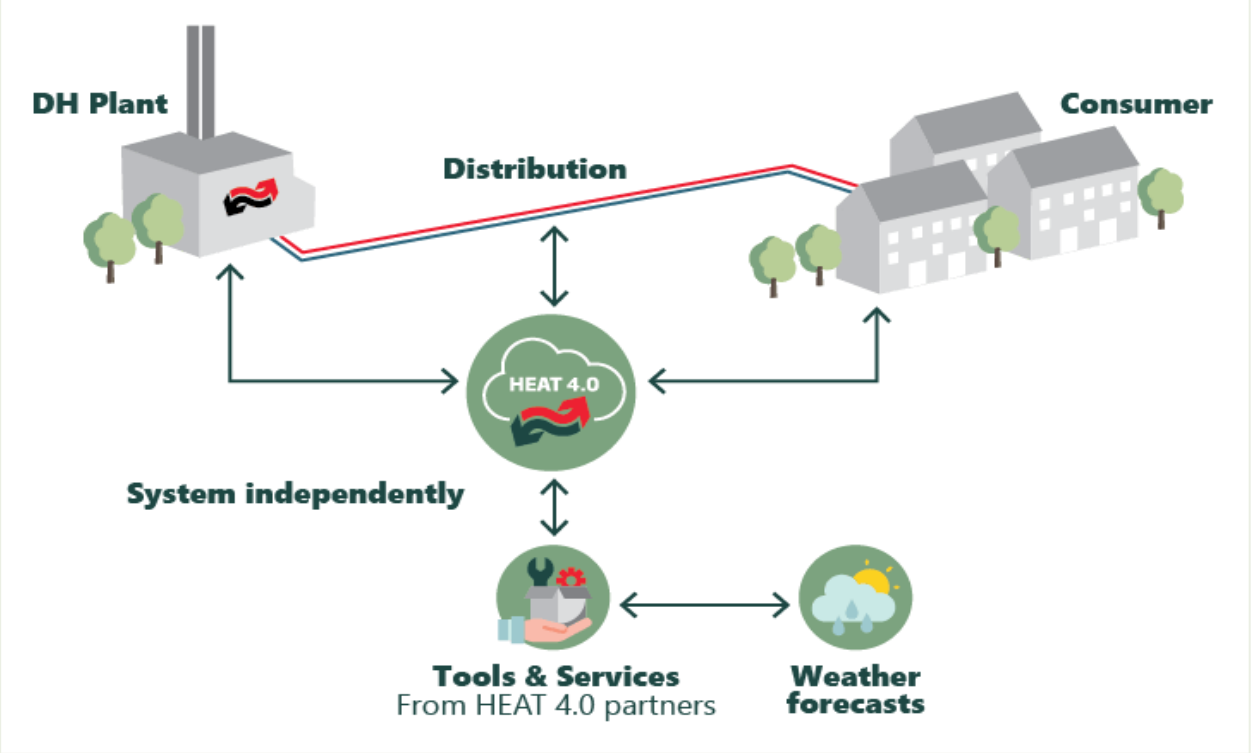


Figure 6: Introduction of standards and protocols and a common HEAT 4.0 platform *into the DH infrastructure.*

The Covid-19 pandemic and regulations limited the access to buildings and the district heating plants dramatically and prolonged the installation period for the monitoring and control solutions by Neogrid and Leanheat in buildings and the solution by Enfor at the DH operator plants. This resulted in a situation where not enough buildings could be recruited to the project. The consequence of this is the lack of enough buildings that could impact the district heating network operation in a quantity that could be measured. Hence a baseline comparison was not achieved and final integration in the CSO was only demonstrated in single buildings and not the complete network or subnet. This subject is discussed in relation to the development of a methodology for 'baselining' and evaluation by Danish District Heating Association in the results section of this report.

Further details can be found in the HEAT 4.0 report on Cross System Optimization to be found at the project homepage https://heatman.dk.

7. Trefor Varme, Kolding

Trefor is a part of a concern structure that combines various utility services. IT and digitalization are a matter of the concern leadership, hence the heating part cannot decide such matters and HEAT 4.0 had to obey these regulations. This prolonged the early integration decisively for this case and the implementation of the CSO. At the same time, the high ambitions concerning IT did inspire the HEAT 4.0 project a lot and especially the idea of the plug'n play thoughts. The cyber security issue and GDPR regulation issues are therefore addressed in the project due to these high requirements by the Trefor concern structure.

When Trefor was joining the HEAT 4.0 project, the company was chosen to increase the variability of technical and organizational characteristics of involved partner plants. Trefor does not produce heat themselves, but rather buy it from another concern part, EWII. In this way, solutions like the CSO could be tested under difference configurations comparing to the other involved district heating companies. At the early stage of the project period, we did not know that the buildings would not be sufficient to make an impact and would be excluded this case from the testing of the CSO solution until further work.

As a consequence, the Trefor case was not working with the CSO, but rather the overall integration with external services, the Common Infrastructures (Cloud component), cyber security and other topics. A diagram of the HEAT 4.0 communication implementation at Trefor is presented in Figure 7. Important for this communication chain is, that Trefor has only one interface with its surroundings through the HEAT 4.0 cloud solution. At the time of implementation, the Science Cloud provided by DTU was used and hosted by Center Denmark, but in near future, the Science Cloud will be replaced by the 'Commercial Cloud' provided by Center Denmark.

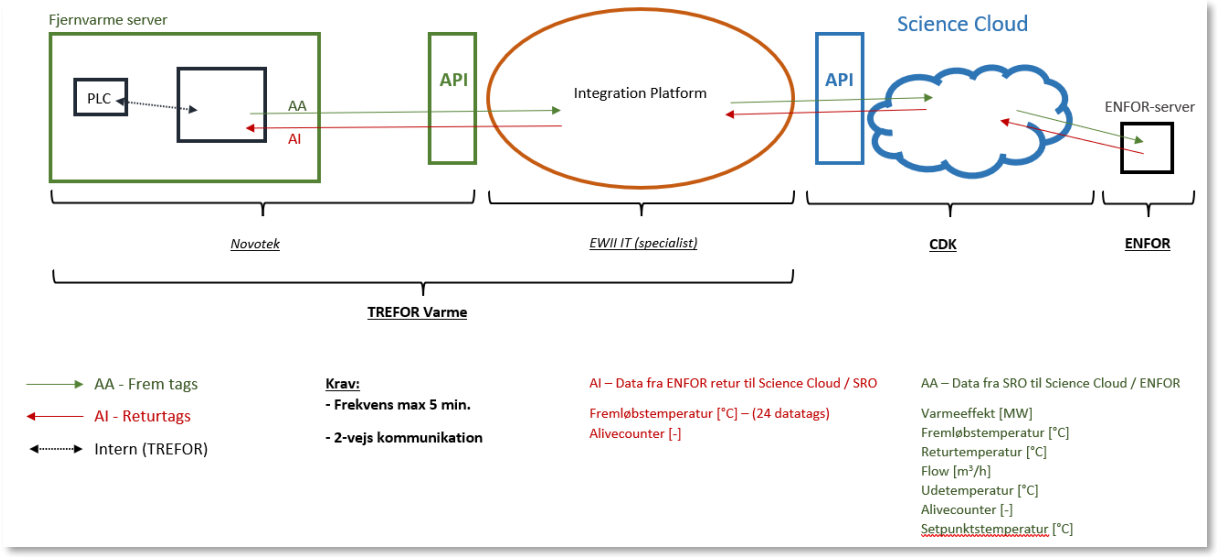


Figure 7: Communication for HEAT 4.0 in Trefor, Kolding, Denmark.

Trefor did invest in:

1) HeatSolution by Enfor incl. service and operation. The solution is a package of services dedicated to the district heating market. On basis of localized weather forecasts, it predicts the heat load for a given DH system and optimizes the supply temperature leading to minimalized heat losses in the network (and other optimization targets). The solution was developed and tested at a single network and will be rolled out to the whole system in 2022.
2) Commercial Cloud provided by Center Denmark, expected in Q3 2022.

Trefor is satisfied with these investments, expecting a saving of at least 2% or approx. 1 mill. DDK, which is achieved by reduction of heat losses in the piping network due to reduction of supply temperature in the overall network. Simple payback by the investment is expected to be 2-3 years.

On top of this achievement, Trefor experiences the following derived values:

- Improved stabilization of operation due to reduced temperature variations in the network and less stress on piping materials.
- Less operational issues and easier surveillance.
- One of the operation KPIs is a so-called 'out-time', where the operation has to be stopped for any reason, amongst these are extreme temperatures and pressure. In case of temperature issues, a stop would be necessary. Due to a reduction of these conditions, the out-time for the system is minimized, impacting the evaluation of the ISO quality assessment.
- Compared to TERMIS-TO, the previous temperature-optimization system, the operation is improved with less out-time and less demand for manual maintenance. This however is due to the outsourcing of the IT operation for the Enfor solutions, where the TERMIS installation has been hosted locally. A finding in this is, that IT operations at plants demand access by the IT specialists, which is demanding and expensive. An external operation may improve these aspects.
- Where the TERMIS solution demanded manual surveillance, the Enfor solution does automatically inform the operators by information and alarms, which leads to fast and precise reactions.
- Adjustments on software, algorithms and surveillance solutions can be done through the internet and do not demand interference with the daily operation.

A more detailed evaluation on basis of TERMIS simulations that apply real weather and demand data for the involved heating seasons is evaluated below.

Through this investment Trefor gained the following:

- A TO-optimization and control that is efficient, stable and releases staff resources.
- An IT solution which can integrate various services without compromising cyber-security and privacy for heat customers.
- Possibility for professional consultancy delivered by Enfor on operational issues, both IT and optimization of our operation.

Trefor expects a Commercial Infrastructure (Cloud) that offers an "app-store" like solution, where services can be combined from different software providers without adjustments to the cloud integration. [Integration is executed by the cloud provider, releasing the DH operator to act as IT experts.]

Integrations could include:

- Leakage detection
- Optimization and control of pumps (incl. CSO)
- Surveillance of overall operation
- Analysis of net topologies and other planning aspects involving system data
- Analysis of user heat demands

Our heat customers gained the following from the HEAT 4.0 project:

- Reduced heat losses in their installation parts = lower operation cost = lower heating cost
- More stable operation, where the hours (outage), where the system is not meeting the demands, are reduced.

Trefor has invested in the HEAT 4.0 solution through the TO-optimization and will adopt e.g. pump optimization solution and leakage detection solution based on IoT monitoring by Desmi and Kingspan/Logstor expects to integrate the commercial cloud by Center Denmark as soon as possible.

For the future of HEAT 4.0, it is essential to gain widespread knowledge of the Cloud and the solutions that can be offered. The foundation for a common platform and its use from it is only strengthened by increasing the volume.

Trefor's recommendation is to offer a HEAT 4.0 solution to the small DH operators in a cooperative solution, limiting the demand for IT knowhow e.g. cyber security and protection of privacy at these small DH companies that do not have the skilled staff to meet these demands. The role of integrators and the role of a common cloud provider by Center Denmark, seem decisive in this proposal.

Concerning the HEAT 4.0 consortium, future common business propositions need to take into account the already significant investments that have been made for partners of HEAT 4.0 when new partners/users are to be connected.

A last recommendation to the HEAT 4.0 consortium would be to interview all partners and existing commercial users of HEAT 4.0 solutions (e.g. District Heating companies in Assens, Sindal, Skive, Ikast, Middelfart, HOFOR and more) to analyse the demand by the DH operators and the sector in general and hereafter contributing to further improvements of the HEAT 4.0 platform.

7.1 Evaluation of Trefor case

Data from the first half of 2022 lead to a prediction of the reduction of heat loss of 1,97% ±1,0% due to the effects of implementing HEAT 4.0 tools – counting the entire Trefor network and the whole year 2022 and compared to pre-HEAT 4.0 conditions where TERMIS-TO was applied in operation.

In more detail, the result for the individual network sections and months are shown in the following Figure 8.

Qtab vægte	71BRK	70EGE	70ERR	71GLV	60HVI	60MIDT	60NORD	60SYD	71NRV	70SKB	70SNO	60STR	70TAU	70ULL
Januar	403,0	27,0	2.988,6	2.145,0	875,5	2.633,5	5.185,2	2.119,9	-3.921,3	-1.043,8	-915,3	3.005,1	-106,3	-125,5
Februar	391,5	31,4	3.097,1	1.968,0	941,6	2.393,8	5.636,2	2.896,6	-5.176,7	-1.065,1	-929,7	3.107,5	-119,5	-126,9
Marts	328,4	23,9	2.489,0	1.730,0	620,2	2.579,6	1.839,4	2.375,7	-4.464,1	-834,7	-723,6	2.378,9	-67,2	-201,7
April	427,4	-9,3	1.549,8	1.346,9	122,0	236,3	-711,9	617,2	-3.676,4	-554,8	-502,5	1.493,3	169,3	-279,2
Maj	557,1	-48,2	439,4	946,9	-392,5	-2.371,2	-3.249,2	-1.434,7	-2.894,1	-270,5	-276,2	550,3	398,1	-367,9
Juni	390,7	-43,8	44,4	501,3	-387,9	-2.312,7	-2.922,5	-1.014,9	-1.709,1	-100,4	-128,7	122,9	321,4	-296,5
Juli	365,8	-48,0	-116,3	403,7	-430,8	-2.648,8	-3.227,3	-1.317,6	-1.469,0	-44,0	-87,5	-21,0	310,2	-307,8
August	377,6	-43,6	-2,1	502,8	-374,9	-2.691,6	-2.676,7	-1.148,4	-1.681,0	-94,3	-129,3	134,0	299,6	-296,3
September	417,1	-45,0	55,9	622,3	-375,2	-2.760,6	-2.610,6	-1.326,9	-1.977,3	-126,9	-158,0	228,3	322,9	-318,1
Oktober	480,8	-35,4	621,7	1.084,7	-166,1	-431,2	-1.330,2	-1.301,0	-3.155,3	-349,2	-345,3	889,0	275,6	-299,0
November	440,1	-8,4	1.569,7	1.530,5	287,1	-709,7	827,9	-191,7	-4.246,9	-642,3	-590,3	1.778,7	96,6	-218,4
December	234,1	50,5	3.245,8	1.936,4	1.166,3	3.344,0	5.655,4	2.492,0	-4.936,9	-1.084,9	-941,2	3.169,9	-300,5	-10,2

Figure 8: Difference in heat losses from pre-HEAT 4.0 conditions to the full implementation of HEAT 4.0 at Trefor. (Negative/red values are increased losses).

Figure 8 shows reduced heat losses in positive coloured values in green and yellow and increased heat losses in red/reddish colours. The heat losses are reduced in four subnets, where the three monthly periods with increased heat losses during summer operation and the last has increased heat losses during the whole year. One main reason for this increased heat losses in the subnets is due to the introduction of 'ISO9001 quality certification' at Trefor, and the strengthened criterion for 'downtime', which entails increased supply temperatures and pressure resulting in increased heat losses in the network. In more detail, the demand for supply temperature has been variable between 56 – 58 degrees Celsius where it is at 60 degrees Celsius for the ISO9001 situation. Similarly, the specification for the net pressure has increased from a variable value to a fixed value of 0,4 bar in specified measuring points. The annual saving for 2022 is estimated to 4.034 MWh, which equals approx. 2%, equals near 1 mill. DDK per year in savings.

The used methodical approach (in Danish):

Der er anvendt historisk data for driftsperioder for hhv. TERMIS og HeatSolutions, for hvert hydraulisk område.

Beregn udtryk for T_m ud fra T_{ude}

T_m = T_{middel} er beregnet for hvert hydraulisk område og danner grundlag for en tendenslinje og dermed en ligning, der udtrykt ud fra en udetemperatur.

T_{om} = omgivelses temperatur (årsgennemsnit = 8 °C)

$$T_m\,[°C] = ((T_f + T_r)/2) - T_{om}$$

Dette betyder, at ligningen kan anvendes ved en vilkårlig udetemperatur og derved kan et begrænset datasæt skaleres op til et forventet år.

Tendenslinje for f.eks. Hvidsminde

*Heatsolutions: y= 47,614*EKSP(-0,0022*X)*

Termis: y = 49,26*EKSP(-0,001*X)

T_{ude} for 2021 på månedsbasis på centralt niveau (Udtræk fra SRO-data)

Fordeling af last på centraler fastlægges ud fra SRO-data (produktion / central / måned)

Derefter beregnes T_{m_Diff} (potentialet for samlet temperatur reduktion i ledningsnettet)

$$T_{m\_diff}\,[°C] = T_{m\_termis} - T_{m\_Heatsolutions}$$

8. Commercial Cases

The commercial partners of HEAT 4.0 did utilize the ideas and products of HEAT 4.0 in different combinations on fully commercial plan. In this section, we take a look at such cases.

8.1 Sindal Fjernvarme

The Sindal Fjernvarme is a case where the HEAT 4.0 partners approached the organization on a fully commercial level. The final result of this approach was that a subset of the CSO was installed as a p2p implementation which does not involve any common cloud component. The building component, however, is not included in the first implementation stage. An additional effort was carried out to consider an improved building integration in the CSO by Neogrid, which was not evaluated as an economical value for the company. NIRAS was involved in the extension of the DH network in Sindal towards an additional small town and a planned nursing care home, that is expected to have a large heat demand. Due to lack of timing, these investigations will not lead to reportable results within the timing of the HEAT 4.0 project.

8.2 Assens Fjernvarme

Similar to the Sindal case, the same HEAT 4.0 partners did implement the same 2-component CSO in a p2p implementation at Assens Fjernvarme on a fully commercial basis. It can be mentioned that this case is probably the most advanced heat operator in Denmark because of its wide mix of prioritizable energy and heat sources. According to Anders Andersen from EMD International, this case would not have been possible to model in EnergyPro and EnergyTrade, without the developments that were motivated by the also advanced HEAT 4.0 case in Brønderslev.

8.3 Other Commercial District Heating Cases

Further DH operators were involved in solutions that are applied in HEAT 4.0, inspired by the project: Skive, Ikast, Middelfart, Fredericia, HOFOR and others in Denmark plus international cases in Baltic, Balkan areas and solutions proposed to huge US university campuses by NIRAS, and in Europa and North America by Danfoss.

9. Achievements for the District Heating Association (the sector)

To get an overall perspective of the achievements of HEAT 4.0 we collect in this section the evaluation by the Danish District Heating Association.

The Danish District Heating Association (DDHA) was responsible for the main parts of the dissemination of the HEAT 4.0 project and solutions, and among the activities, several workshops and seminars were carried out. Their commitment to the project is tightly combined with the digital strategy of the association.

DDHA was responsible for the development of a methodology that would enable the evaluation of HEAT 4.0 and in general for the evaluation of the performance of district heating plants. This work is reported in a separate report to be found on the homepage of HEAT 4.0 https://heatman.dk. The main point of this report is that there are no simple ways to correlate adjustments to complex systems like a district heating system and the result hereof. The reason for this is that there are many operational works ongoing in such systems - pipes are renovated, new areas are added to the network, new monitoring systems are introduced, maintenance is ongoing and much more. Hence it is not possible to find the impact of investments or a change onto the performance of a whole system. This finding is very relevant for all actors in fields of complex systems, hence, very valuable.

DDHA was the host of a workshop for invited district heating operators to find values that HEAT 4.0 has generated. The workshop is recorded and can be found that the HEAT 4.0 homepage at https://heatman.dk.

10. Achievements for commercial businesses

There are two types of achievements by the commercial partners, besides organizational issues that are discussed in another section:

a) improvements of the existing software, algorithms and services and
b) new products, services and solutions.

Common for these achievements are the added ability to interact and communicate with other software and services, which is one of the main findings of the holistic approach of HEAT 4.0.

10.1 Common Cloud Infrastructure

As the sketch in Figure 6 shows, the HEAT 4.0 platform provides a 'Common Infrastructure' that could be consisting of many different components to fabric different services. The most prominent of these solutions is the 'common cloud' for data sharing that enables the implementation of the CSO solutions expanding from a peer-to-peer into a 'peer-to-cloud-to-peer' implementation.

10.2 Common Infrastructure (Commercial Cloud) – Center Denmark

Probably the most powerful result of HEAT 4.0 is the common cloud infrastructure, together with the overall organization that enables common business proposals and solutions. In the two first years of HEAT 4.0, DTU Management was the dominating actor, backed closely up by the project leadership NIRAS, also having deep insights into the Science Cloud from the previous CITIES project and a DTU Library project that enabled the building of the Science Cloud, and hereafter the Science Cloud for CITIES. After Center Denmark took over the responsibility for the commercial cloud, the research-oriented Science Cloud was fully integrated with the Center Denmark, hereby the Science Cloud and the Commercial Cloud for HEAT 4.0 are now one single entity, owned by the non-profit organization Center Denmark, supporting both research, development, innovation and commercial activities.

A dedicated report is expected to be placed on https://heatman.dk.

10.3 Cross-System-Optimization by EMD, Enfor, Neogrid, Leanheat and CDK

The Cross System Optimization is one of the main innovation packages done by HEAT 4.0 and is reported in the dedicated report to be found on https://heatman.dk. In this report, the whole concept is described, the individual improvements to the involved software and services are presented, standardized communication is introduced and results are reported. Together with the report by the Center Denmark introduced above, the main aspects of the overall HEAT 4.0 concept are reported, adding up to the current summary.

10.4 Danfoss & Leanheat

Danfoss Heating has improved its District Heating Units, which connect the building to the district heating network. This unit is improved by the company and tested as a part of the HEAT 4.0 project. The improved heating unit is intended to offer flexibility and other services to the district heating network. By adding new sensors as part of the Leanheat approach to optimize the operation of the building heating system, the two partners offer a complete package of control and monitoring for the integration of buildings into district heating systems. Additionally, Danfoss Heating improved its optimization of the domestic hot water (DHW) sub-system. The result is exemplified in Figure 9.

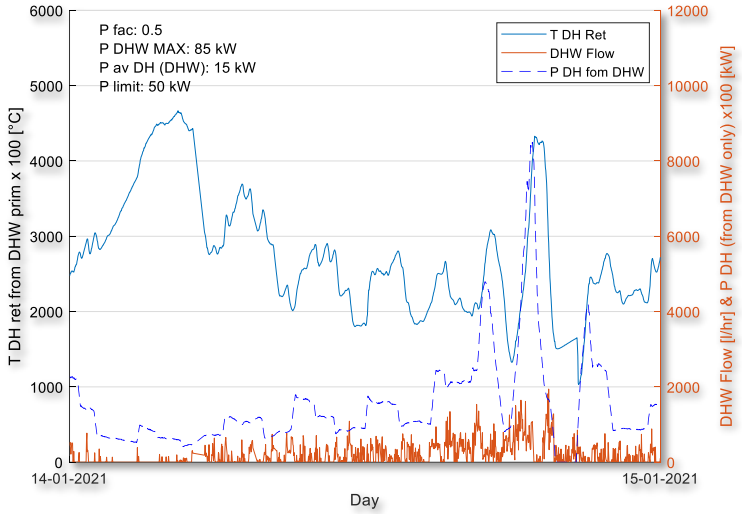


Figure 9: Building control case in Hillerød as an example of an improve domestic hot water control by Leanheat/Danfoss.

The example for the hot water control by Leanheat/Danfoss in Figure 9 shows the problem with 3 peaks (label P DH from DHW), where also the district heating return temperature is high. This should be avoided by distributing the charging more evenly over the whole day.

A further focus is on the high district heating return temperature during nights, where almost no DHW consumption is seen. The tank volume and the circulation losses are the main influencing parameters for optimization of DHW consumption compared to DHW consumption (draw off).

In the Hillerød case, there was implemented a simple control concept which automatically sets limitations to the district heating power and return temperature.

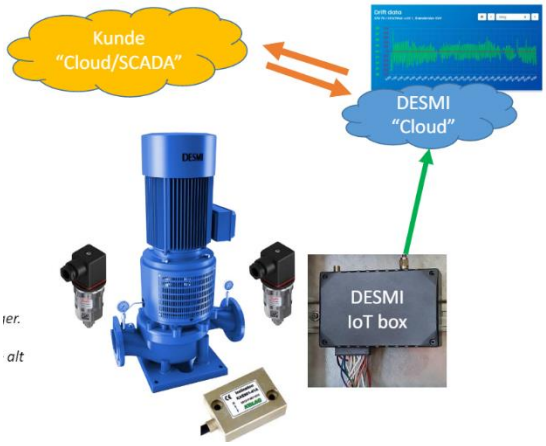
Dynamic simulations of DHW tank charging were collected from the previous Energy Lab Nordhavn project where 2 years of data are available. These data were applied in the HEAT 4.0 project to develop a more advanced and robust control method for hot water services. More results can be expected soon from implementation in Hillerød and Leanheat results from Hillerød and Kolding for the heating season 2021.

10.5 **DESMI**

The objective was to get first experiences with the digitalization of pumps, measurement, data communication/sharing/integration and remote monitoring – in order to be able to build a number of digital services for our clients in the district heating sector, but also for other sectors.

10.5.1 IoT Box – a product initiated by HEAT 4.0

DESMI pump products are improved with monitoring abilities and control solutions that are enabled over the Internet and through mobile Apps. An IoT Box has been developed to support monitoring and data from this component are used as important information for forecasting and cross-system control in the HEAT 4.0 Cross-System Optimization process. The solution is implemented in the Brønderslev case where several pumps are monitored and steadily deliver data remotely to DESMI, where they are analysed and applied in modelling the involved pumps. The planned integration with the CSO at Brønderslev was expected in 2021 but did not occur due to various reasons. It can be emphasized, that the final device and method can be applied to any pump system by any provider (manufacturer agnostic).



The data collection by the IoT Box system, enabled DESMI to provide an optimization service that is built on top of their performance model, by broadcasting alternative operation schedules that a human or machine operator can apply or ignore.

10.5.2 Pump efficiency surveillance (PES)

To ensure high efficiency for pumping, a service is developed that compares the actual operation condition of a pump with its predicted operation, shown as a performance curve established by testing. The service communicates instructions to adjust the control system toward the optimal operation of actual energy, economic performance and lifetime.

10.5.3 Pump maintenance surveillance (PMS)

A tool to support the business unit, service & maintenance of pumps on shore and sea has been a result of the above achievements. The data collected from the pumps over time is compared with a huge backlog of experiences, pointing at the condition of the pumps, necessities for maintenance and possible renovation. This way, such intrusion can be planned with improvements of the overall operation and cost. One observation as a result of this work was, that the installation of extra monitoring equipment is often very demanding, hence, planning is necessary. In this observation, the above IoT box was also involved.

10.5.4 Data sharing

For HEAT 4.0 and the CSO, data sharing is implemented in a REST API interface. The values for temperature, flow, pressure before and after the pump, vibration, power demand, some information from the inverter and control signals from the optimization, are shared through this interface.

PS: It can be mentioned that the district heating solutions are similarly applied on new markets for AquaCultures, production of fish and aquatic products.

10.5.5 Test cases

There were carried out tests on operational pumps at Brønderslev Forsyning within the HEAT 4.0 activities. In these tests, also pumps from other manufacturers and old pumps were involved. When doing this, the surrounding system has to be understood and included in the optimization considerations, e.g. the control abilities of the setup are defined by the involved components and their limitations. Additional monitoring equipment had to be installed, such as flow meters that are very expensive at the given flow volumes (>30.000 DKK) etc. An alternative approach was developed to compute the flow on basis of the pressure before and after the pump.

10.5.6 Dashboard Tool

The result of the above work is a tool 'DESMI Pump cloud – Dashboard'. The tool gives a geographic overview of the pumps position for the customer. The dashboard shows the measurements and the computed flow life. Operators can use it for continuous surveillance.

10.5.7 Extra value from HEAT 4.0

Due to the tools from HEAT 4.0, DESMI did meet the requirements of the clients from the Aquaculture sector, producing fish and underwater products. These processes demand multitude of pumps of the size as in district heating, hence an interesting expansion for DESMI. The demand for uptime is however very high, hence the surveillance very important. Operators of aqua culture installations do contract the responsible to the component providers, hence DESMI is able to provide such services that where developed partly in HEAT 4.0.

The first observation from the case in Brønderslev was, that the pumps were running with extremely frequent up- and down regulations that reduce the service lifetime of pumps. DESMI could transfer the experience to this new sector, aquaculture, to provide a more stable and long-term performing regulation, without compromising requirements.

Another observation was that the customers did only want the very necessary data, but the complementary data is to be utilized for the service program by DESMI and is not wasted.

One extra finding from the aqua systems is, that the clients want their data back into their SCADA systems, not involving external clouds or fancy mobile apps. Hence this approach adds more 'architecture' to the p2p and p2c2p architectures. The new architecture can be called peer to API to peer (p2api2p).

All this digitalization is so extensive that it must be taken seriously by resource allocations and partnerships, which is the actual stage of DESMI, where they have to decide on these very large investments.

The new system is already sold before the final stage of the software development to two companies: Aalborg Portland and Danish Salmons. There is a new tool in the pipeline 'Generic pump API'. This dashboard will be improved to present automated pump reports and a business revenue model has to be found for the IoT Box.

10.5.8 Optimization of pumps incl. CSO

Based of the achieved IoT concepts, a full-scale test facility is built by DESMI and due to the HEAT 4.0 developed concepts, this is able to be monitored and operated remotely. This test facility is used for specialist education and the reproduction of problematic observations from the real world, thereby gaining insights and solutions to critical conditions. The test facility is also used for the analysis of pump characteristics for the modelling of prediction and optimization models of pumps. These models are then involved in the CSO that was developed at Brønderslev Forsyning, but the results need evaluation in future work. A commercial integration with the HEAT 4.0 concept is expected in the future.

10.6 LOGSTOR

Logstor, now Kingspan, has considered various contributions to HEAT 4.0 amongst these the described.

10.6.1 Leakage detection in district heating pipes

The objective of Logstor was to work on leakage detection. All three partner district heating companies in HEAT 4.0 have installed and connected the leakage detection system from LOGSTOR. The main findings are that such systems have to be commissioned at the beginning to ensure proper services. For example, initial errors were found, where wires were not connected properly - problem solved and hereafter all systems worked as expected. There was no

further cross-company service in HEAT 4.0 due to a lack of interest in this topic, despite the fact that the value of pipes is the largest in every DH company.

Due to a lack of interest in leakage detection, Logstor decided to work on IoT monitoring and digital tools that can help with early decisions for project designs and long-term planning, hereby matching the research work carried out by DTU Management in the HEAT 4.0 project in the activity A12 (long-term planning). Designing an IoT solutions was similar to the demands at DESMI, but no coordination was wished by these two partners.

10.6.2 IoT monitoring system

Logstor promotes its own IoT device and belonging software and cloud infrastructure.

A first version of an IoT toolbox with a temperature sensor is developed in HEAT 4.0 in close cooperation with NIRAS. The system includes IoT-enabled sensor(s) communication, a wireless MQTT protocol is adopted and a cloud service with a mobile app developed. Communication with the surroundings is enabled through a standardized API communication interface that enabled integration with among others the HEAT 4.0 platform. The goal of this setup was to support fast debugging and continuous monitoring of heat pipes.

10.6.3 Pipe Invest – A tool for investment decision making

The tool Pipe Invest is an investment decision-making software tool for the economic evaluation of design and maintenance of district heating pipes. This solution was developed in cooperation with NIRAS.

10.7 Kamstrup

Kamstrup is the provider of Smart Meters and software services to monitor buildings and networks. Within HEAT 4.0, Kamstrup did not develop new software but contributed with data communication to research and analyses, prediction services and the CSO solution.

Brønderslev Forsyning has completed a demonstration case, where data from Diehl meters were used by Kamstrup to support similar solutions – and not based on data from their own smart meters.

Parallel to the partner work in HEAT 4.0, Kamstrup, Enfor and EMD did propose a Cross System Optimization solution, strictly commercial to the two district heating companies: Sindal Fjernvarme and Assens Fjernvarme. Other cases are not reported to HEAT 4.0 but are confidential commercial activities done by the partners.

11. Scientific achievements within HEAT 4.0

Science results within HEAT 4.0 aim at developing generic algorithms and solutions. These results are provided by the university departments of DTU and Aarhus University and research groups of Danfoss and Grøn Energi, that is the research and development department of the Danish District Heating Association. Results from this work is placed in a dedicated report that can be found on the HEAT 4.0, heatman.dk and the CITIES homepage.

Part 3
Products, Services and Solution List

The HEAT 4.0 project did develop a various set of results that are promoted to the district heating actors. Below, the list shows different services that customers from the district heating sector can purchase through the HEAT 4.0 partners, including Integrator-services.

12. Cross System Services - CSS

Cross System Services (CSS) is a HEAT 4.0 generic term that is applied for any kind of service or product that operates across the district heating system. At the time of the application, there were two main CSS defined:

1) an optimization solution, across the technical components, production, network and demand side (buildings)
2) an optimization solution across the temporal axis, from daily operation over short-term to long-term planning.

As we worked on these aspects, we observed that there are as well a number of other services that go across other aspects of the system. In the same time, not all partners were agreeing on the term "cross system optimization" with a central control component. This subject will be discussed below in more detail. Due to these reasons, the overall term CSS was aimed at reaching a more neutral notion to fit all kinds of services, software and products that go across any aspects of the district heating system.

13. Cross System Optimisation – CSO

The term, Cross System Optimisation (CSO) was defined as a main innovation from the beginning on the HEAT 4.0 project. As we worked on the implementation of the concept, it turned out that the different partners had different ways of seeing this unknown and new solution. At the time of writing the application to the Innovation Fund Denmark, DTU Compute was in charge of this work. Due to the maternity leave of the responsible, it was agreed that this 'activity' is led by Enfor. To keep the complexity of the task manageable, the p2p concept was proposed by the company.

13.1 CSO Peer-to-peer implementation – CSO p2p

Cross System Optimization involved the partners from Enfor, EMD, Neogrid and Leanheat, whereas the academic side intentionally was kept in a track separated from the implementation part, to avoid even higher complexity.

In the first years of effort, a common understanding of a peer-to-peer (p2p) sketch was developed by the partners. The idea was very simple at first – e.g. any partner would compute a time series for 7 days ahead (time range was chosen to ensure that thermal tank storage could be involved) with hourly timesteps. And a schedule with a 7 day a

head timeseries would be available to any kind of communication interface. In this way, anybody could pick the timeseries they demand. No orchestration was planned.

While working with the p2p concept, it turned out that different kinds of solutions could be combined and already were combined. Hence the term of applying cross system services was even more relevant and the cross system optimization turned out to be a covering term in itself. Different implementations were based on the same principles by different partners in different combinations. Hence the p2p proves to be a strong architecture from a business point of view. The different combinations will be listed in the solution list, Error! Reference source not found., below.

13.2 CSO Peer-to-cloud-to-peer implementation – CSO p2c2p

NIRAS did interpret the CSO from the beginning with a common central piece of architecture that would handle common tasks such as the orchestration between the individual solutions during optimization. Due to a lack of agreement and the fact that the involved partners did prefer a p2p implementation, the solution with a central piece of architecture was stalled and planned to be taken up, when the partner, responsible for the common cloud, would be able to implement such a solution. Here the change between DTU Management that was running the Science Cloud, the involvement of NorthQ who was planned to run the commercial cloud, and later the involvement of the Center Denmark, is the important reason for the result today with respect to the CSO p2c2p solution. An independent report with a detailed presentation of the concept is published on the homepage https://heatman.dk.

Demonstration and solution list

In this section we try to identify services and demonstration cases that help the reader to grasp the wide application of HEAT 4.0 concepts.

Table 4: Demonstration and solution list.

Name	Provider	Description
HEAT 4.0 Ready Label	HEAT 4.0 Consortium	The HEAT 4.0 Steering Committee promotes a label "HEAT 4.0 Ready" for analogue and digital solutions that meet the requirements for integration with the HEAT 4.0 overall concept.
Standardized communication between HEAT 4.0 partners	All software solution partners	The consortium introduced on basis of the above HEAT 4.0 Ready label, standardized data communication and sharing. On basis of this, every partner improved and adjusted their involved software solutions.
Improvements on software	All software solution partners	Every software partner did improve their solution decisively. The details can be read in the 2-pagers by the companies at www.heatman.dk An example is the application of research solutions into the newest version for prediction, and another example the application of smart meters into the algorithms of the software solutions.

Data exchange for DH operators	Brønderslev Forsyning Trefor Hillerød Forsyning	Implementation of standardized communication interface on basis of OPC-UA, alternatively and less recommended MQTT or others.
CSO p2p	All partners	Implementation of communication interfaces for all involved partners as REST-API. Neogrid demonstrates a standardized Rest-based API, where others use ftp, sftp and any other communication protocols and solutions.
CSO p2p	Brønderslev Forsyning EMD, Enfor, Neogrid	Achieved full implemented CSO involving all partners, where the building side is not involved in the combined optimization due to lack of buildings.
CSO p2p	Hillerød Forsyning EMD, Enfor, Neogrid	Partner implementation: Similar to the case in Brønderslev.
CSO p2p	TREFOR Enfor, Leanheat	Achieved partial implemented CSO where the distribution side was in focus and the integration with the commercial cloud decisive (will be achieved in autumn 2022).
CSO p2p	Sindal Forsyning Enfor, EMD, Kamstrup	Commercial deal: - Kamstup provides Enfor with information on the monitored buildings. - Enfor includes this knowledge in their network optimization. - EMD uses the prediction of Enfor (demand and temperature) in their planning. - No feedback loop involved. -
CSO p2p	Assens Fjernvarme Enfor, EMD, Kamstrup	Similar implementation as in Sindal
CSO p2c2p	Center Denmark	Demonstrator tool developed and tested. Final commercial service is expected in Q3 2022.
CSO p2c2p	Center Denmark	Data sharing service developed, tested and running on the Science Cloud.

		Final commercial solution with 24/7 service is expected in Q3 2022.
Integrator service	NIRAS/Danfoss	At the international markets, NIRAS is the Integrator (single-point-of-contact), supporting the clients with initial analysis, first business proposals, implementations and commissioning. Danfoss is able to blend their Leanheat Solution and HEAT 4.0 solutions. At Danish DH sites, every HEAT 4.0 partner may perform the integration role.
CSO by Danfoss End to end solution	Leanheat/Danfoss	The Danfoss concern, including Leanheat and parts of Enfor, has a variation of the HEAT 4.0 concept that aligns with an end-to-end solution. Such solutions can be delivered by Danfoss-owned partners, or in combination with other HEAT 4.0 partners.
IoT Device Box & Services	DESMI	An IoT solution for the monitoring of any kind of large-scale pump on the market. This is a new product from DESMI that was not implemented without the help of HEAT 4.0 partners, especially the consultant service by NIRAS.
CSO Integration Service	DESMI	On basis of data from, among others the IoT solution above, DESMI has demonstrated to be able to integrate pump predictions into the CSO described above. This solution is tested in Brønderslev, but not commercially fully developed (future work planned).
Predictive maintenance of pumps, worldwide	DESMI	On basis of the IoT solution, DESMI developed a 'surveillance solution' that are able to monitor pumps online in the whole world. This approach is then applied for an new service of 'predictive maintenance' of pumps globally and also for competing products.
IoT Device Box & Services	Kingspan/LOGSTOR	An IoT solution for the monitoring of district heating pipes by cheap solutions. This is a new product from Kingspan/Logstor that was not implemented without the help of HEAT 4.0 partners, especially the consultant service by NIRAS.
Predictive maintenance solution for DH networks	Kingspan/LOGSTOR	On basis of the IoT solution, Kingspan/Logstor developed a 'surveillance solution' that are able to monitor district heating networks online in the whole world. This approach is then applied for an

		new service of 'predictive maintenance' of pumps globally and also for competing products.
DH network planning tool	Kingspan/LOGSTOR	The company has developed a calculator for the life-cost computation and planning of district heating networks.

Part 4
Publication and dissemination

14. Professional and Public Publication list

This list of publications includes any kind of communication that was/is available for the HEAT 4.0 project, hence including written articles and results from the Communication work package.

6. *Alfred, H. (2020a). HEATman—A smart digital toolbox for district heating. Hot | Cool, 75(1), 28–30.*
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12. *Heller, A., & Lange, E. (n.d.). HEAT 4.0—Digitalt understøttet fjernvarme – Præsentation ved Danske Fjernvarme—(Open access version—Scanned).*
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15. Scientific Literature List incl. Conference Activities

The scientific production of the HEAT 4.0 partners is rather large. In the following the effort is made to present all the publications and conference presentations within the project. However further literature and activities could be found in the future, because some submitted papers may not be published at the time of writing this list.

Homepages with additional information on HEAT 4.0:

https://heatman.dk

https://smart-cities-centre.org

List date: 16. Aug. 2022 – updates can be found at the above referenced homepages.

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72. Thorsen, J. E., Busk, S., Frederik, Gynyel, F., & Wahlroos, M. (2021). *Insights on Domestic Hot Water Consumption for Multi Flat Buildings*. 7th international Conference on Smart Energy Systems.
73. Wu, J., Niu, Z., Huang, L., Nielsen, P. S., & Liu, X. (n.d.). Understanding Multi-Scale Spatio-Temporal Energy Consumption Data: A Visual Analysis Approach. *Energy*.

16. HEAT 4.0 Arrangements, Events and 'HEAT 4.0 Monthly' meetings

The project communication is handled by a monthly online meeting that was started due to the Covid-19 pandemics, to enable cross-partner communication. One of the bi-products is a set of recorded presentations that are valuable for interested parties in HEAT 4.0. These can be found on the homepage https://heatman.dk/events/.

List of events from 16. August 2022:

16.1 Upcoming events

The HEAT 4.0 consortium will contribute to the following conferences, events and happenings.

- Smart Energy System Conference the 13.-14. Sept. 2022 in Aalborg, Denmark [LINK to event]
- National meeting for Danish District Heating Association the 27.-28. October 2022 in Copenhagen [LINK to event]
- HEATman Workshop in Serbia in September 2022 by NIRAS
- Swiss District Heating Association, Professionals evening the 8. Sept. 2022 – HEAT 4.0 and Danish technologies by Alfred Heller, NIRAS [LINK to event]

16.2 Historical events

16.2.1 Steering Committee meetings

There have been Steering Committee meetings since March 2019 – all in all, 16 meetings until Aug. 2022. The 22nd of august is the end date of the Innovation Fund project, which will be completed by this final report.

16.2.2 List of events

Below, the list of events do not represent all activities that the partners of HEAT 4.0 have been delivering during the project, but it gives a good idea of the very active community of the project.

DATE	PRESENTER	EVENT	LINK AND INFORMATION
7, 2022	Marta Murkowska, EMD; Torben S. Nielsen, Enfor; Pierre Vogler-Finck, Neogrid inkl. Leanheat	HEAT 4.0 Monthly – HEAT 4.0 Monthly – Cross System Optimization – Final Results	Video: [Comming soon]; PDF(Marta): CSO Concept Recap AND The Production Component AND Value evaluation at Brønderslev Forsyning; PDF(Torben): The Network Component; PDF(Pierre): CSO Concept Recap AND The Building Component;
6, 2022	Amos Schledorn, PhD, DTU Compute	HEAT 4.0 Monthly – Optimization for long-term planning connected to the demand side of District Heating 'Frigg' AND Bidding strategy modelling with uncertainties	PDF (Frigg): Presentation PDF (Bidding): Presentation Video: [LINK to recording]

5, 2022	Steen Kramer Jensen, Digitaliseringsekspert, Danske Fjernvarme; Alfred Heller, Head of HEAT 4.0, NIRAS; Søren Skov Bording, Center Denmark; Henrik Madsen, DTU Compute; Helge Schlott Hansen, TREFOR Varme	Afsluttende workshop om HEAT 4.0 og HEATman-projektet	PDF (Steen): Presentation PDF (Alfred): Presentation PDF (Søren): Presentation PDF (Henrik): Presentation PDF (Helge): Presentation RESOURCES: Presentations are collected at HEAT 4.0 site
5, 2022	Michael Lassen Schmidt, Head of Section, NIRAS	Sales meeting for DH operators in Beograd, Serbia	PDF: Presentation of HEATman by NIRAS
5, 2022	Lars Troldahl, Sales Manager Optimization Software, District Energy, Danfoss Climate Solutions	HEAT 4.0 Monthly – End to end solution to achieve the transition by Danfoss	PDF: Presentation Video: [LINK to recording]
4, 2022	Francesco Gaballo, PhD. DTU Management AND Michael Lassen Schmidt, Head of Department, NIRAS	HEAT 4.0 Monthly – European study on system scenarios AND evaluation of business opportunities.	PDF (Francesco): Presentation; PDF (Michael): Presentation Video: [LINK to recording]
3, 2022	Diverse	HEAT 4.0 Monthly – Approaching the markets	No resources to this session
2, 2022	Jan Erik Thorsen, Director, DBL Application Centre, Danfoss	HEAT 4.0 Monthly – Hot water systems impacting the district heating	PDF: Presentation Video: [LINK to recording]
1, 2022	Martin Lindgaard Pedersen, Divisional Head, Digital, Kingspan (previous Logstor) Peter Jorsal, Product-/Academic Manager, Kingspan Jacob Foldager, Business Development Manager, Aquaculture, Desmi Pumping Technology A/S	HEAT 4.0 Monthly – The industrial perspective on HEAT 4.0	PDF (Kingspan): Presentation PDF (Jacob): Missing Video: Recording

16.2.2.1 Before 2022

DATE	PRESENTER	EVENT	LINK AND INFORMATION
12, 2019	Alfred Heller and Michael Lassen Schmidt, NIRAS	Keynote: HEATman DBDH Member meeting in Odense	Seminar
9, 2021	Jan Erik Thorsen, Danfoss; Frederik Stjernholm Busk, TREFOR Varme A/S Firat Günyel, Hillerød Forsyning	Insights on domestic hot water consumption for multi-flat buildings	CONFERENCE: 7th Smart Energy Systems Conference,

	Mikko Wahlroos, Danfoss Lean-heat		Copenhagen PDF: Presentation
9, 2021	Jan Erik Thorsen, Danfoss; Frederik Stjernholm Busk, TREFOR Varme A/S Firat Günyel, Hillerød Forsyning Mikko Wahlroos, Danfoss Lean-heat	Insights on domestic hot water consumption for multi-flat buildings	CONFERENCE: 7th Smart Energy Systems Conference, Copenhagen PDF: Presentation
4, 2021	Alfred Heller, NIRAS Poul Vestergaard, Brønderslev Forsyning Mikkel Westenholz, Enfor Henrik Madsen, DTU Compute	DBDH Seminar: HEAT 4.0 – Digitally supported District Heating	5 presentations are collected on the HEAT 4.0 sharing site
4, 2021	All partners	General Assembly – HEAT 4.0	Morning Session: 17 presentations and recording of session Afternoon Session: Recording of session available on HEAT 4.0 Sharing Site
12, 2020	Thorkil Neergaard, Brønderslev Forsyning Anders Andersen, EMD Henrik Madsen, DTU Compute	Presentations regarding HEAT 4.0	PDF: Presentation PDF: Presentation PDF: Presentation
12, 2020	DTU Management and NIRAS	Workshop Data Lake for HEAT 4.0 (Science Cloud)	No resources available
12, 2020	DTU Compute and partners	Technical Workshop	No resources available
12, 2020	Danfoss, Neogrid and 'Grøn Energi	Workpackage meeting	No resources available
12, 2020	Partners	Sales meetings: Svebølle-Viskinge DH, Energy Cluster Denmark, DBDH Germany, Vidensby Lyngby, Tartu, Estonia	No resources available
11, 2020	Many HEAT 4.0 partners	Internal workshops	No resources available
11, 2020	Many HEAT 4.0 partners	Green Digitalization 2020 – Joint International Conference	PDF: Homepage
11, 2020	Many HEAT 4.0 partners	Final Conference for CITIES – Contribution by HEAT 4.0	No resources available

10, 2020	Danske Fjernvarme	Seminar: Grønne unfordring – varme svar	No resources available
10, 2020	Danfoss, Neogrid and 'Grøn Energi	3 presentations by HEAT 4.0 partners	CONFERENCE: 6th Smart Energy Systems Conference, Aalborg
10, 2020	Danfoss, Neogrid and 'Grøn Energi	Communication Work package Meeting	No resources available
10, 2020	All HEAT 4.0 partner workshop	11 presentations by HEAT 4.0 partners	Presentations collected by HEAT 4.0
9, 2020	Danske Fjernvarme	Seminar: Security for critical energy infrastructures	No resources available
9, 2020	DTU Management, Center Denmark and NIRAS	Workshop on cloud solutions	No resources available
9, 2020	Alfred Heller, NIRAS	Webinar for IEA DHC – How can HEAT 4.0 change the business case of the DH sector?	No resources available
6, 2020	Center Denmark and NIRAS	Workshop on Commercial Cloud take over	No resources available
6, 2020	DTU Management, DTU Byg and NIRAS	Workshop on research activities: Long-term planning, Stochastic modelling and digital twins	No resources available
6, 2020	Kamstrup and NIRAS	Workshop on Smart Meetering in HEAT 4.0 and CSO	No resources available
6, 2020	Trefor Varme and NIRAS	Workshop on implementations at Trefor	No resources available
6, 2020	Alfred Heller, NIRAS	Webinar for IEA DHC – Cooperation between IEA Annex and HEAT 4.0	No resources available
05, 2020	Alfred Heller, Project Leader HEAT 4.0, NIRAS	Sales meeting District Heating Association in Switzerland	No resources available
5, 2020	DTU Compute, Danfoss under the lead of NIRAS	A communication strategy for HEAT 4.0	No resources available

4, 2020	Alfred Heller, NIRAS	Webinar for IEA DHC – HEAT 4.0 – Digitally Supported District Heating – An Introduction	PDF: Presentation
4, 2020	All partners	General Workshop for HEAT 4.0 in Aarhus	No resources available
3, 2020	Desmi and NIRAS	Dashboard development for pump surveillance	No resources available
3, 2020	All partners at NIRAS Aarhus	Workshop on common data and components	No resources available
3, 2020	Brønderslev Forsyning, Enfor and NIRAS	Implementation activities in Brønderslev, data, CSO, and others	No resources available
3, 2020	Grøn Energi, NorthQ and NIRAS	Screening, baslining and commercialisation	No resources available
2, 2020	Center Denmark and NIRAS	Initial contribution to HEAT 4.0	No resources available
2, 2020	DTU Compute and NIRAS	Research tracks for HEAT 4.0	No resources available
1, 2020	Enfor and NIRAS	Workshop: CSO draft	No resources available
1, 2020	NIRAS	Workshop: TERMIS integration in HEAT 4.0	No resources available
12, 2019	Frederik Stjernholm Busk, TREFOR Varme A/S	Workshop: Data communication at Trefor Heating	No resources available
12, 2019	Michael Lassen Schmidt, Head of Section, NIRAS	Sales meeting Nyborg, Denmark	No resources available
12, 2019	Alfred Heller, NIRAS	HEATman projektet – fremtidens digitale platform	Ingen ressourcer tilgængelige
11, 2019	Alfred Heller, NIRAS	iEnergi – Digitalisering: Dataadgang og dataanvendelse	Seminar
11, 2019	Case modelling at Hillerød DH, EMD, Enfor, Neogrid, Leanheat, NIRAS	Modelling the District Heating Case in Hillerød	No resources available
11, 2019	Brønderslev, EMD, Enfor, NIRAS	Modelling the District Heating Case in Brønderslev	Seminar

10, 2019	NIRAS	DBDH Webinar: Digitalisation of District Heating – challenges and opportunities for the utility sector	https://dbdh.adobeconnect.com/digitalisation-of-district-heating/
10, 2019	All partners	HEAT 4.0 Workshop at NIRAS Aarhus	No presentation available
10, 2019	NIRAS	NIRAS' services for District Heating – HEATman included North America Campus and contactor Energy Accelerator Academy IV	No presentation available
9, 2019	Alfred Heller, NIRAS	Keynote: HEATman – Digitally supported District Heating	CONFERENCE: 5th Smart Energy Systems Conference, Copenhagen
9, 2019	NIRAS and DESMI – Follow up	Workshop: Pump Services in HEAT 4.0	No resources available
8, 2019	NIRAS	Commercialization: VEKS, Copenhagen	No resources available
8, 2019	NIRAS and DESMI	Workshop: Pump Services in HEAT 4.0	No resources available
6, 2019	NIRAS and NorthQ	Workshop: A Commercial Cloud – What could it be?	No resources available
6, 2019	NIRAS	Commercialization: Tartu, Estonia	No resources available
6, 2019	Frederik Stjernholm Busk, TREFOR Varme A/S	Workshop: Multi-Family Buildings	No resources available
12, 2019	Alfred Heller, NIRAS	Danske Fjernvarme: Temadag om morgendagens fjernvarmeteknologier	PDF: Presentationer
12, 2019	Alfred Heller, NIRAS	HEATman intro og DBDH fokus eksport og værdier	PDF: Et forsøg på at skrue det hele sammen – til fordel for værkerne – forretning/samfund/miljø
11, 2019	Alfred Heller, NIRAS	Danish: iEnergy, Dansk Energi – Digitalisering: Dataadgang og dataanvendelse	PDF: Data – Perspektiver fra HEATman
10, 2019	Alfred Heller, NIRAS	CONASENSE SME Buisiness Tracks	PDF: Presentation

6, 2019	Frederik Stjernholm Busk, TREFOR Varme A/S	Workshop: Multi-Family Buildings	No resources available
6, 2019	Vilhjalmur Nielsen, DTU Buildings	Workshop between DTU, Denmark and NTNU Norway	No resources available
4, 2019	Frederik Stjernholm Busk, TREFOR Varme A/S	Workshop: District Heating companies demands towards HEAT 4.0	No resources available
4, 2019	Micheal Lassen Schmidt, NIRAS	Presentation of HEAT 4.0 and HEATman to the International DBDH event in Budapest	PDF: Presentation
3, 2019	Press Releases	Numerouse news post in local new channels and online portals (Search online for 'HEAT 4.0'	Collection by the project energiforskning.dk adds the project to the Official Research Database of Danish Energy Research
3, 2019	All HEAT 4.0 partner workshop	6 presentations by HEAT 4.0 partners	Presentations collected by HEAT 4.0
19-03-2019	HEAT 4.0 Kick-Off, Aarhus	4 presentations by HEAT 4.0 partners	Presentations collected by HEAT 4.0

16.2.2.2 HEAT 4.0 Monthly Meetings – Before 2022

DATE	EVENT
Dec 2021	Long-term planning by DTU Management
Nov 2021	The Commercial Cloud by Center Denmark
Oct 2021	Cross System Optimization – Final implementation plans by EMD, Enfor, Leanheat and Neogrid
July-Sept 2021	Summer vacation
June 2021	Various presentation by DTU Compute
Maj 2021	The Commercial Cloud – A first plan by Center Denmark
April 2021	A HEAT 4.0 Webinar for the whole consortium
Marts 2021	Towards common goals by NIRAS
Feb 2021	Cross System Optimization – A first idea by Enfor, EMD, Neogrid and Leanheat

Jan 2021	Administrative topics by NIRAS
Dec 2020	Publications in HEAT 4.0
Nov 2020	A first industrial view on HEAT 4.0 by Danfoss, DESMI and Logstor
Oct 2020	The Science Cloud in HEAT 4.0 – An introduction and perspectivation
Sept 2020	Value and markets by DTU Management
Aug 2020	Experiencing HEAT 4.0 by Brønderslev Forsyning, Trefor Varme and Hillerød Forsyning
since Aug 2020	HEAT 4.0 Monthly (Online) Meetings are introduced to tackle the CORONA restrictions.

16.2.3 Other interesting dates in chronologic order

Sept 2017	Alfred Heller joins NIRAS, coming directly from DTU Byg and actually hired by AU in a position as a Assoc. Prof. in the building section, all later partners of HEATman and HEAT 4.0.
Jan 2018	A cooperation committee agrees on a weekly meeting schedule for the 'HEATman' application project. Before this NIRAS, DTU and AU where contacting individual partners to investigate their interest in HEATman (later HEAT 4.0). In this European projects and other applications where applied for.
8. Oct. 2018	Interview of consortium by Innovation Fund Denmark
15. Nov. 2018	Kick-of for HEAT 4.0 at Innovation Fund Denmark
7. Dec. 2018	NIRAS internal news that HEAT 4.0 is a reality.
19.-20. March 2019	Steering Committe Meeting No. 1 Official Kick-off meeting at NIRAS in Aarhus, Denmark.