Deliverable 6.5

Summer School on Industrial Heat Pump technology

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31/07/2025	0.1	First draft
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1st edition of the SPIRIT Summer school on high-temperature industrial heat pumps – report review

In the framework of SPIRIT work package on Dissemination and Raising Awareness – the SPIRIT Summer School on high-temperature industrial heat pumps took place in Copenhagen, Denmark, in June 2025.

This first edition of the summer school was held at the DTU Lyngby Campus from June 16 to June 27 and was attended by 31 students: 8 Master's students, 16 PhD students, and 7 representatives from industry.

The activity was mainly organized by DTU, in collaboration with EHPA and with the support of the three research organizations (RTOs) involved in the project: TNO, DTI, and DLR. The curriculum was drafted by DTU with input from the RTOs, while EHPA contributed to logistics and dissemination of the school before, during, and after its implementation.

This intensive 10-day course combined lectures, expert talks, site visits to real-world and pilot high-temperature heat pump applications as well as networking opportunities for the participants. Additionally, to earn 5 ECTS credits, students were required to complete a group project to demonstrate their acquired knowledge.

The detailed agenda of the programme (Annex I) as well as some pictures of the lectures and pilots visits (Annex II) are attached below. A short video of the summer school was also created and disseminated on SPIRIT's Linkedin page after the activity took place and it can be found here.

Following the lectures, a satisfaction survey was distributed to the attendees to gather feedback on the quality of the activity. The results of the survey, based on 11 responses, are presented below and will provide improvements to future editions of the summer school.

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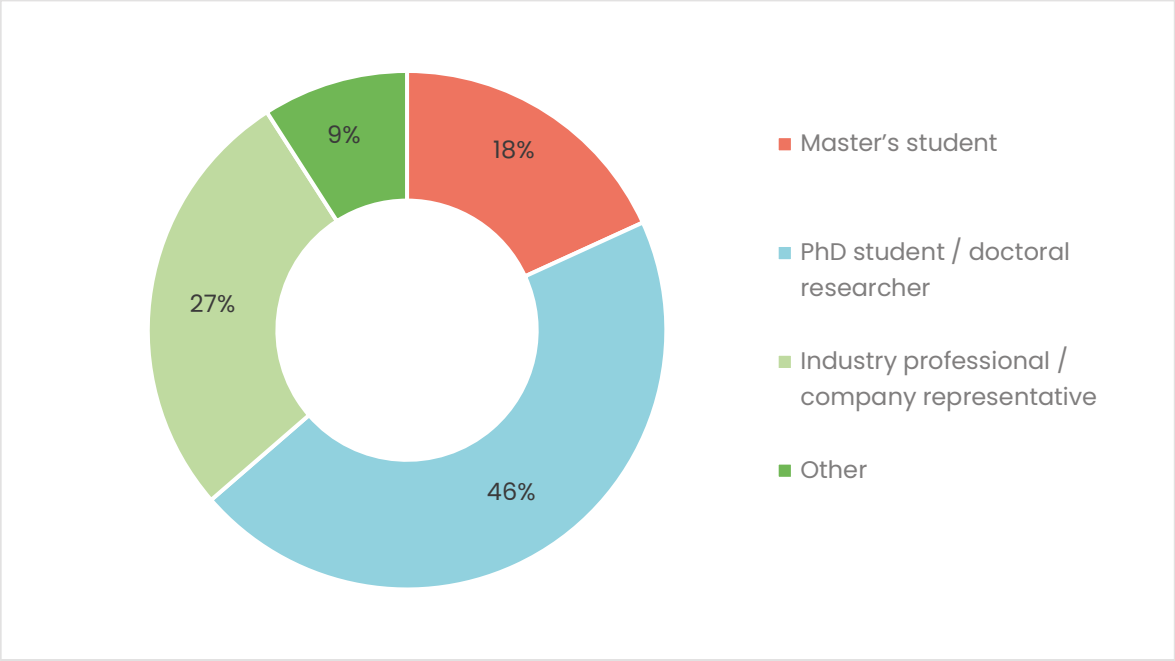
Satisfaction Survey Results

The satisfaction survey shared after the summer school was composed of 12 questions with the aim of:

- Profiling the students;
- Identify their level of satisfaction with the overall course and with specific activities included in the training (lectures, demonstration sites visits, project work, networking opportunities;
- Collect the attendees recommendations and suggestions on how to improve specific parts of the training.

Here below the questions and outcomes of the survey are shared:

1. **What best describes your current role or affiliation?**



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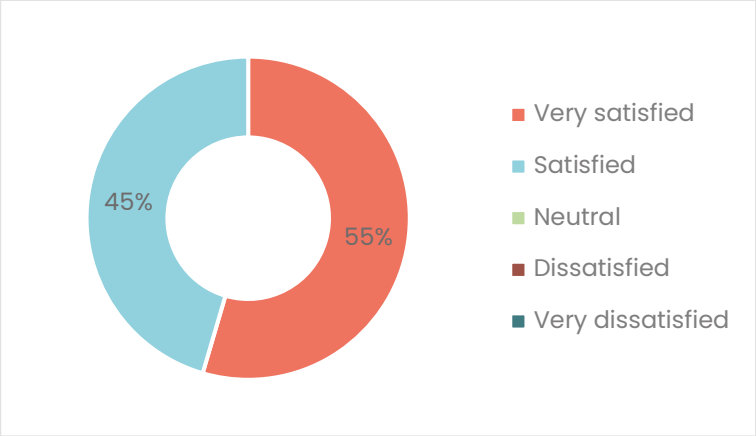
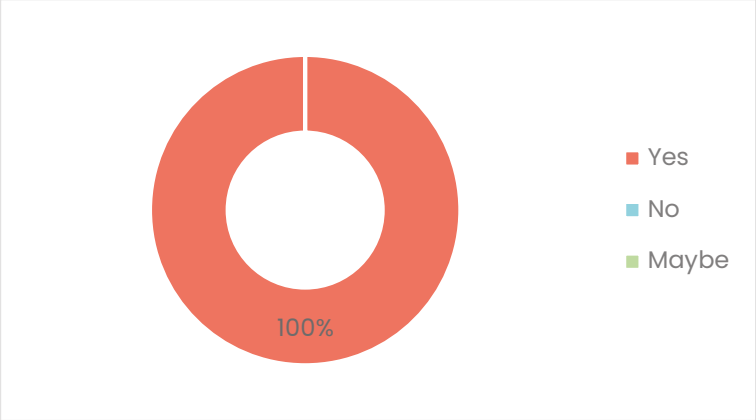
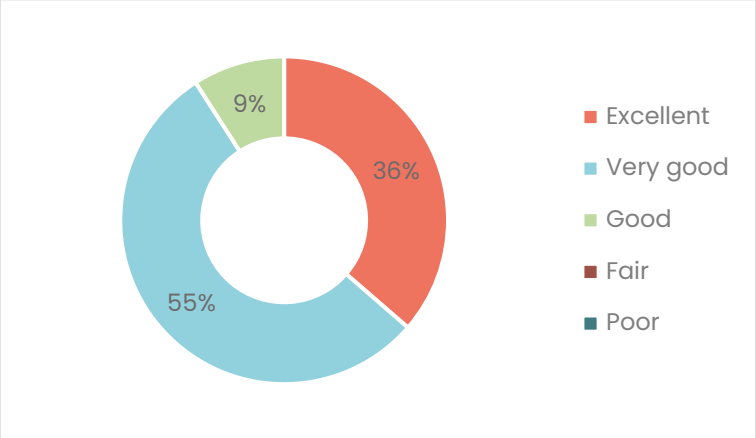
2. **How satisfied were you with the summer school overall?**



3. **Would you recommend it to a peer?**



4. **How would you rate the lectures and speakers?**



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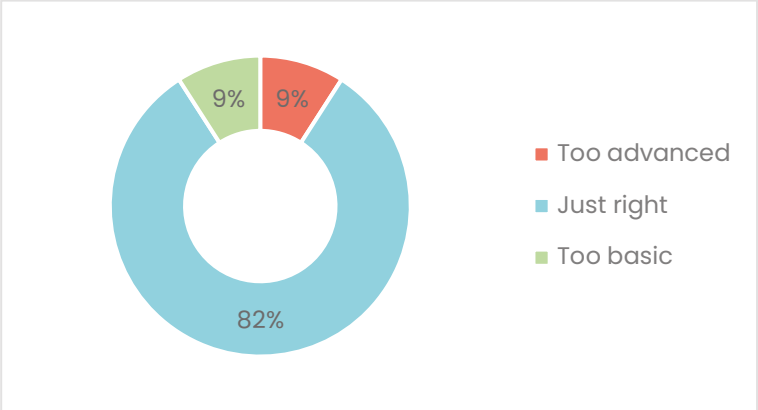
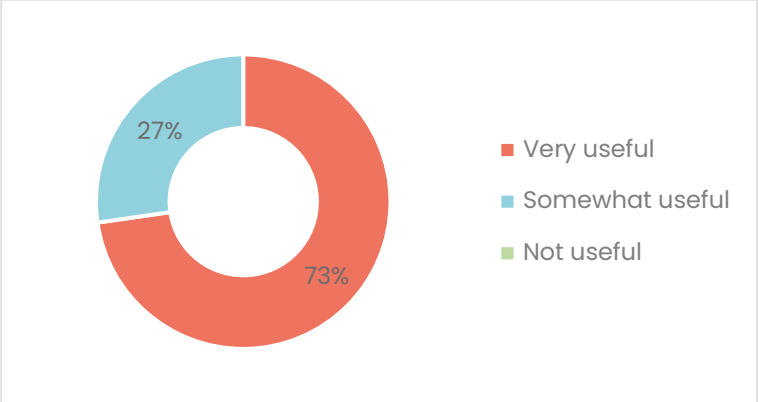
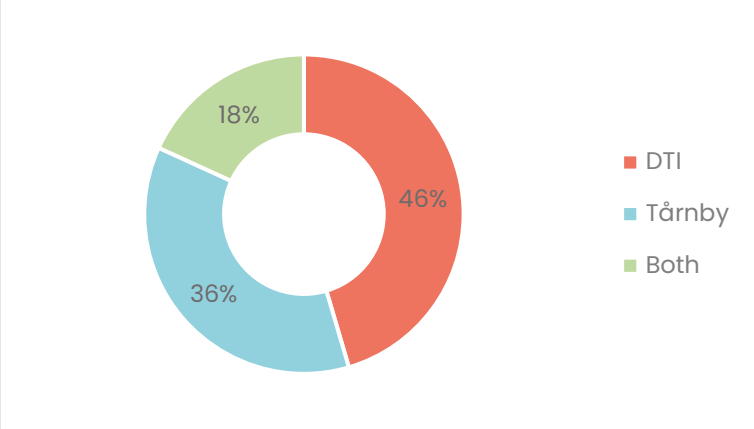
5. **Was the content level appropriate for your background?**



6. **How useful were the demonstration sites visits?**



7. **Which demonstration site visit did you find most valuable, and why? Do you have any suggestions for improvement?**



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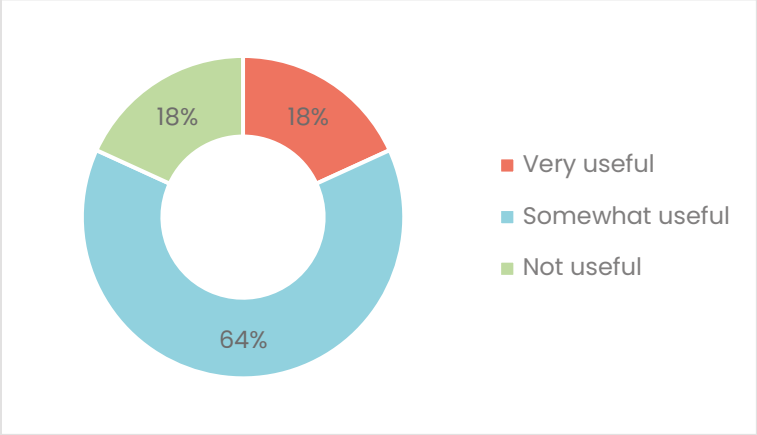
Main positive notes

- Variety of heat pumps and refrigeration systems displayed at DTI.
- Seing an actual active plant at the Tarnby site was very interesting.
- The speakers were very passionate about their work while presenting the demos.

Main suggestions for improvement

- Providing prior preparation or a short briefing before the site visit on what will be shown would make it more engaging and easier to understand.
- Allowing more time for the visits would be beneficial.
- Dividing participants into smaller groups could make the visits more effective.

8. How useful was the group project activity for learning?



9. Do you have any comments or suggestions regarding the project activity?

The students feedback can be summarised in 4 main points:

- Clarify project requirements early – Provide clear instructions and expectations from the start, possibly using one shared example project to guide participants step by step.
- Rebalance project content – Reduce time spent on pinch analysis and allow more focus on heat pump design, cycle configurations, and integration.

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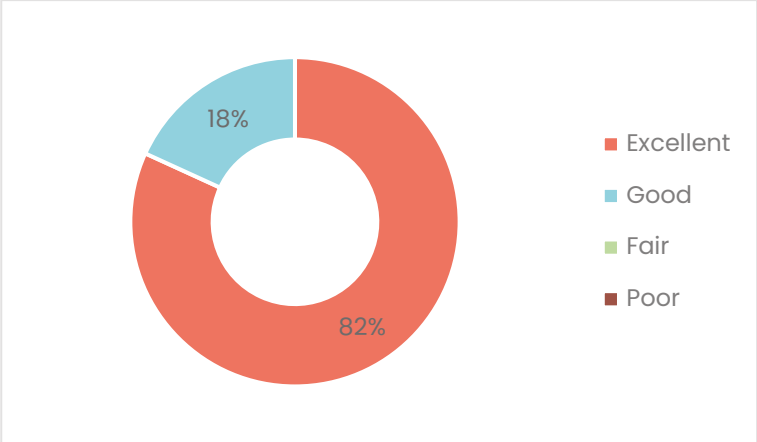
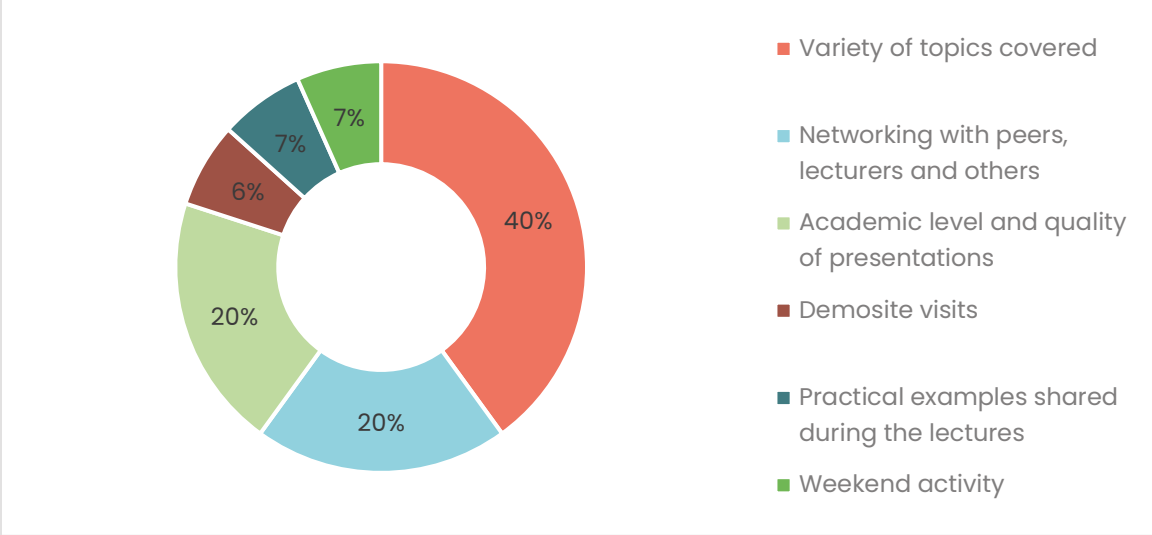
- Incorporate guided exercises – Include short, practical, hands-on sessions (with worked-out examples and solutions) to help participants apply methods directly during the course.
- Adjust project timing and format – Consider starting the main project after the course, while using course time for structured exercises and smaller group activities to encourage engagement.

10. How was the social dinner/networking experience?



11. Overall, what did you like the most?



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12. Do you have any overall suggestions for improvement?

Some felt that two full weeks in presence was a bit too much. A suggestion was to split it into one week in person and one week online, or to allow participants—especially from industry—to sign up for just one week depending on the topics. Week 1 could then focus on the basics, while week 2 covers more advanced material.

In terms of content, participants would have liked more time on P&IDs of real systems to see how they differ from theory, and more on heat pump control, such as PID controls and interactions between components. It was also suggested to put more focus on general heat pump cycles, including pros/cons and example calculations, while going less deep into heat exchanger and compressor modelling. Instead of many short pilot examples, one full case study in detail—covering design, modelling, and control—was preferred. A guest lecture on industrial symbiosis (such as Kalundborg symbiosis or Green Lab Skive) was also proposed.

On the practical side, suggestions included providing slides before lectures when possible, choosing a classroom with better air and closer to the canteen, avoiding overlapping presentations, and encouraging lecturers to be more interactive and enthusiastic.

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ANNEX I – DETAILED AGENDA OF THE SUMMER SCHOOL

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SPIRIT Summer school

Industrial high-temperature heat pumps for decarbonization of industrial process heating

General information

Dates: June 15th – June 27th (last class will end at 14:00 on the 27th)

Location: Technical University of Denmark, Copenhagen (Lyngby)

Scope & Form: The class is taught all week days from 8-17. The Teaching will be a combination of lectures, Q&A sessions and supervised project work. An industrial case will be chosen on the first day. There will be time each day to implement the tools and methods taught to the industrial case.

Evaluation: The final assessment is based on a submission consisting of one abstract and one poster on the industrial case study (submission date 1/9-2025)

Workload: 5 ECTS

Confirmed speakers

Adriano Sciacovelli	Technical University of Denmark
Benjamin Zühlsdorf	Danish Technological Institute
Carlo De Servi	VITO
Emil Buur Trads	Johnson Controls Sabroe
Gabriele Fregonese	SINLOC
Johan Van Beek	Danfoss
Jonas Kjær Jensen	Technical University of Denmark
Jonas Lundsted Poulsen	Danish Technological Institute
Jozefien Vanbecelae	European Heat Pump Association
Laura Alonso Ojanguren	Technalia
Martin Stage Pihl Andersen	Danish Technological Institute
Manuel Gräber	TLK Energy
Maximilian Kriese	The German Aerospace Center (DLR)
Miguel Ramirez	TNO
Nitish Anand	VITO
Panagiotis Stathopoulos	The German Aerospace Center (DLR)
Wiebke Meesenburg	Technical University of Denmark
Xabier Peña Anton	Technalia

Social events

Sunday June 15th	Welcome reception and opening ceremony
Thursday June 26th	Dinner in Copenhagen

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Agenda and curriculum

Day 1: Decarbonization of Industrial Process Heat	
Monday June 16th	**Speakers:** • Martin Stage Pihl Andersen - Danish Technological Institute • Jonas Kjær Jensen - Technical University of Denmark **Location:** DTU Building 421 – Room 002
	09:00-10:00 - Welcome and course introduction
	10:00 – 12:00 Session 1: **Introduction to industrial process heat & decarbonization** • Overview of current process heat technologies in different industrial sectors (Food & Beverage, Paper & Pulp, Chemical, Pharmaceutical) • Economic and environment impact of industrial process heat • Decarbonization strategies: indirect electrification, direct electrification, integration of renewable energy • Cost savings and emissions reduction potential for decarbonization of industrial process heat • Technical, non-technical and economic barriers for decarbonizing industrial process heat
	12:00 – 13:00 Lunch
	13:00 – 15:00 Session 2: **Introduction to industrial heat pumps** • Heat pump working principles, work driven and heat driven cycles • Heat pump performance measures • Thermodynamic limits for infinite & finite Reservoirs • Second Law and exergy-based performance measures
	14:30 – 15:00 Coffee and afternoon snack
	15:00 – 16:30 Session 3: **Student case introduction** • Presentation of industrial cases • Peer discussion session, case selection & group formation • Project work

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Day 2: Process integration and techno-economic analysis of HTHP	
Tuesday June 17th	**Speakers:** • Manuel Gräber - TLK Energy • Jonas Kjær Jensen - Technical University of Denmark **Location:** DTU Building 421 – Room 002
	09:00 – 12:00 Session 1: **Process Integration and Pinch Analysis** • Introduction to Process Integration and Pinch Analysis: composite curves, pinch point, pinch based guidelines for HTHP integration • Step-by-step guide on conducting Pinch Analysis including examples from industry • Energy Savings Potential via pinch analysis and energy demand management • Introduction and Step-by-Step Guide to TLK Pinch Analysis Tool • Emerging trends and methods in Process Integration and Pinch Analysis
	12:00 – 13:00 Lunch
	13:00 – 15:00 Session 2: **Techno-economic analysis of HTHP integration** • Estimation of CAPEX & OPEX for HTHPs • Break-even COP • Economic analysis and viability of HTHPs • Levelized cost of heat for industrial process heat
	15:00 – 15:30 Coffee and afternoon snack
	15:30 – 16:30 Project work and supervision

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Day 3: HTHP Technologies – Cycles & Working Fluids	
Wednesday June 18th	**Speaker:** • Jonas Kjær Jensen - Technical University of Denmark • Johan Van Beek – Danfoss **Location:** DTU Building 421 – Room 002
	09:00 – 12:00 Session 1: **Thermodynamic cycles and working fluids for HTHP** • Overview of HTHP working fluids: o Classification of working fluids synthetic vs. natural o Environmental impact of working fluids o Safety and technical constraints • Overview of HTHP cycles: o Vapour Compression Cycles (Rankine), o Gas Cycle (Brayton) o Transcritical Cycles o Zeotropic Mixture Cycles • Advanced cycle layouts for HTHP o Two-stage cycles o Cascade cycles o Open-cycles
	12:00 – 13:00 Lunch
	13:00 – 14:00 Session 2: **Industrial HTHP in practice** • Component design for high temperature heat pumps • Safety and compliance
	14:00 – 15:00 Session 3: **Modelling and Simulation of HTHP** • Overview of modelling tools and resources for: o EoS and thermodynamic properties o Component libraries o Equations solvers for systems non-linear equation
	15:00 – 15:30 Coffee and afternoon snack
	15:30 - 16:30 Session 3 (continued): **Modelling and Simulation of HTHP** • Model development methods o Control Volume equations o Constitutive equations o Auxiliary and closure equations o Degree of Freedom

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Day 4: HTHP Technologies – Compressors for HTHP	
Thursday June 19th	**Speakers:** • Panagiotis Stathopoulos - The German Aerospace Center (DLR) • Xabier Peña Anton – Technalia • Emil Buur Trads – Johnson Controls Sabroe **Location:** DTU Building 421 – Room 002
	09:00 – 10:30 Session 1: **Compressor technology overview** • Working principles of HTHP compressors o Volumetric compressors – reciprocating and screw o Dynamic compressors – centrifugal and axial • Application range of the above HTHP compressors in terms of capacity, pressure and temperature
	10:30 – 12:00 Session 2: **Dynamic Compressors** • Design and optimization of axial and centrifugal compressors • Technical constraints of axial and centrifugal compressors • Operational and part-load performance of axial and centrifugal compressors
	12:00 – 13:00 Lunch
	13:00 – 14:45 Session 3: **Volumetric compressors** • Lubrication of compressors and HTHP lubricants • Design and optimization of reciprocating and screw compressors • Technical constraints of reciprocating and screw compressors • Operational and part-load performance of reciprocating and screw compressors
	14:45 – 15:00 Recap and final remarks
	15:00 – 15:30 Coffee and afternoon snack
	15:00 – 16:00 Session 4: **Lab tour - DTU Construct refrigeration and Heat Pump Lab** Weel & Sandvig R718 heat pump with centrifugal compressor
	15:00 – 16:30 Session 4: **Project work and exercises.**

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Day 5: HTHP Technologies – Heat exchangers for HTHP	
Friday June 20th	**Speaker:** • Carlo De Servi – VITO • Nitish Anand – VITO • Xabier Peña Anton – Technalia • Martin Stage Pihl Andersen – Danish Technological Institute **Location:** DTU Building 421 – Room 002

	09:00 – 10:00 Session 1:
	Heat exchanger technology overview
	• Working principles of HTHP heat exchangers
	  o Plate Heat Exchangers
	  o Shell and Tube Heat Exchangers
	  o Shell and Plate Heat Exchangers
	• Application range of the above HTHP heat exchangers in terms of capacity, pressure and temperature

	10:00 – 12:00 Session 2: **Dimensioning of single-phase and two-phase (condensers & evaporators) heat exchangers** • Fundamentals of heat exchanger design • Estimation of heat transfer coefficients • Estimation of friction factors and pressure loss • Advanced heat exchanger design methods
	12:00 – 13:00 Lunch
	13:00 – 14:00 session 3: • Evaporator and condenser design in practice
	Session 4: **Steam generation heat exchangers and heat pumps** • Concepts of steam generation heat exchangers • Dimensioning of steam generation systems • Operation of steam generation systems
	15:00 – 15:30 Coffee and afternoon snack
	15:30 - 16:30 Session 5: **Project work and supervision**

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Day 6: Excursion to Danish Technological Institute (DTI) Århus	
Monday June 23rd	**Speakers:** • Benjamin Zühlsdorf - Danish Technological Institute • Jonas Lundsted Poulsen - Danish Technological Institute **Location:** DTI in Århus
	The Bus will leave from DTU at 07:00 and will return to DTU and approx. 20:00. **Session 1: Insights from Annex 58:** • Overview of available HTHP technology and close to market technologies. • Integration concepts for HTHPs **Session 2: Guided tour at DTI heat pump test center** **Session 3: HTHP integration in practice:** • SPIRIT project demo. case – sugar industry • EEETHOS project demo. case – asphalt industry • EEETHOS project demo. case – superheated steam drying

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Day 7: HTHP Integration in practice	
Tuesday June 24th	**Speakers:** • Laura Alonso Ojanguren - Technalia • Maximilian Kriese - The German Aerospace Center (DLR) • Miguel Ramirez – TNO **Location:** DTU Building 421 – Room 002
	09:00 – 12:00 Session 1: **Experience from HTHP Demonstration projects** • SPIRIT demonstration cases o Paper & pulp o Food industry – shrimp processing • Push2Heat demonstration cases o Chemical industry o Paper & pulp
	12:00 – 13:00 Lunch
	13:00 – 14:00 Session 1 (continued): **Experience from HTHP Demonstration projects** • EEETHOS demonstration cases o Paper & Pulp o Roof tiles
	14:00 – 15:00 Session 2: **Highly integrated heat pump-based processes** • CHASE – MVR heat pump with latent thermal storage • Food Industry – Potato frier
	15:00 – 15:30 – Coffee and afternoon snacks
	15:30 – 16:30 **Project work and supervision**

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Day 8: Heat storage and flexibility	
Wednesday June 25th	**Speakers:** • Wiebke Meesenburg - Technical University of Denmark • Adriano Sciacovelli - Technical University of Denmark **Location:** DTU Building 421 – Room 002
	09:00 – 12:00 Session 1: **Heat storages for high temperature process heat** • Heat storage methods and mechanisms • Heat storage modelling approaches¨ • HTHP and heat storage integration
	12:00 – 13:00 Lunch
	13:00 – 15:00 Session 2: **Flexibility and ancillary services** • Electric boilers etc. for operational synergy with HTHPs • Heat demand flexibility • Power consumption flexibility and ancillary services
	15:00 – 17:00 Session 3: **Industrial site visit - District Heating Heat Pump: Tårnby Forsyning**

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Day 9: Business modes & regulatory frameworks	
Thursday June 26th	**Speakers:** • Gabriele Fregonese – SINLOC • Jozefien Vanbecelae – EHPA **Location:** DTU Building 421 – Room 002
	09:00 – 10:00 Session 1: **Project work and supervision**

	10:00 – 12:00 Session 2:
	Business models for HTHPs
	• Introduction to business models
	  o Definition and importance
	  o The business model canvas
	  o Detail of the components of the BM canvas
	• Risk and uncertainty in economic analysis
	  o Definitions and types of risks
	  o Measuring, managing and hedging risks
	  o Decision-making under uncertainty
	  o The cost/price of risks
	• Business models in the energy sector and servitization
	  o "Traditional" manufacturing and sale
	  o Leasing
	  o Energy-as-a-Service and Heat-as-a-Service

	12:00 – 13:00 Lunch

	13:00 – 15:00 Session 3:
	EU regulations for heat pumps and HTHP integration
	• Regulatory framework for industrial electrification
	  o EU's legislation on industrial decarbonisation
	  o Current policies such as RED, CID
	• Financial incentives for adoption
	  o Overview of the existing financial barriers
	  o Proposed mechanism to overcome those barriers
	• Waste heat recovery
	• Regulatory framework for waste heat recovery

	15:00 – 15:30 – Coffee and afternoon snacks
	15:30 – 16:30 Session 2 (continued):

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Day 10: Industrial case presentations	
Friday June 27th	**09:00 – 12:00 Session 1:** **Status presentations and peer-review session** All students will present the progress they have made on the industrial cases. Students and instructors will give feedback on the projects and give recommendations for future work.
	12:00 – 13:00 Lunch
	13:00 – 13:30 Session 2: **Concluding Remarks and farewell**

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ANNEX II – PICTURES OF THE LECTURES AND DEMONSTRATION SITES VISITS

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Auditorier
Databar
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Learn for Life


1. Economics – Electricity to gas price ratio
Opex recommendations: Tax


SPIRIT
Risk and Uncertainty in Economic and Financial Analysis


DANISH
TECHNOLOGICAL
INSTITUTE


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GÆST


GÆST