Course guide
820763 - AET - Thermal Energy Storage

Last modified: 13/03/2025

Unit in charge: Barcelona School of Industrial Engineering
Teaching unit: 724 - MMT - Department of Heat Engines.

Degree: MASTER'S DEGREE IN ENERGY ENGINEERING (Syllabus 2013). (Optional subject).
MASTER'S DEGREE IN INDUSTRIAL ENGINEERING (Syllabus 2014). (Optional subject).
MASTER'S DEGREE IN ENERGY ENGINEERING (Syllabus 2022). (Optional subject).

Academic year: 2025 **ECTS Credits:** 5.0 **Languages:** English

LECTURER

Coordinating lecturer: Ivette Rodríguez Pérez

Others: Ivette Rodríguez Pérez
Joaquim Rigola Serrano
Castro Gonzalez, Jesus

PRIOR SKILLS

Fundamental aspects of thermodynamics, fluid mechanics and heat transfer and mass transfer

REQUIREMENTS

Those equivalent to have passed the Master leveling course

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
CEMT-1. Understand, describe and analyse, in a clear and comprehensive manner, the entire energy conversion chain, from its status as an energy source to its use as an energy service. They will also be able to identify, describe and analyse the situation and characteristics of the various energy resources and end uses of energy, in their economic, social and environmental dimensions, and to make value judgments.
CEMT-5. Employ technical and economic criteria to select the most appropriate thermal equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technological applications in the production, transportation, distribution, storage and use of thermal energy.
CEMT-7. Analyse the performance of equipment and facilities in operation to carry out a diagnostic assessment of the use system and establish measures to improve their energy efficiency.
CEMT-6. Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage and use of electric energy.

TEACHING METHODOLOGY

-Lecture or conferences (EXP): Lectures taught by the professors of the course as well as invited lectures.
-Interactive classes (parts): resolution of exercises, collective discussions with both the teacher and the students. Presentation by the students of exercises carried out individually or in small groups.
-Oriented theoretical-practical works (TD): completion of a classroom activity, theoretical or practical, carried out individually or in small groups with the teacher's guidance.
- Project, activity or work of reduced scope (PR): Self-learning based on accomplishing an activity of reduced scope, individually or in small groups, just applying the knowledge acquired.
- Project or work of broader scope (PA): Self-learning based on accomplishing an activity of broader scope, individually or in small groups, just applying the knowledge acquired.
- Assessment exam (EV).

LEARNING OBJECTIVES OF THE SUBJECT

In the course a description of the new energy paradigm of distributed generation is presented. In this panorama the accumulation of thermal energy / thermochemical plays an important role in order to decouple power generation from consumption. It also gives a detailed description of the technologies most used in thermal and thermochemical energy storage such as thermal energy storage for sensitive and / or latent heat, fuel and cooling adsorption and absorption.

STUDY LOAD

Type	Hours	Percentage
Self study	85,0	65.38
Hours large group	30,0	23.08
Hours small group	15,0	11.54

Total learning time: 130 h

CONTENTS

Energy audits

Description:
Energy, exergy and other performance indicators. Using energy storage and heat pumps. Distributed generation and energy storage systems: co-generation, thermal cycles, heating and cooling networks.

Specific objectives:
Review concepts of energy and exergy efficiencies
Introduce students to the concept of distributed energy.

Related activities:
-Lectures or conferences
-Interactive classes
-Oriented theoretical-practical works
-Project, activity or work of reduced scope
-Project, activity or work of broader scope

Related competencies :
CEMT-5. Employ technical and economic criteria to select the most appropriate thermal equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technological applications in the production, transportation, distribution, storage and use of thermal energy.
CEMT-1. Understand, describe and analyse, in a clear and comprehensive manner, the entire energy conversion chain, from its status as an energy source to its use as an energy service. They will also be able to identify, describe and analyse the situation and characteristics of the various energy resources and end uses of energy, in their economic, social and environmental dimensions, and to make value judgments.

Full-or-part-time: 17h
Laboratory classes: 4h
Guided activities: 2h
Self study : 11h

Sensible heat storage

Description:
Passive and active systems. Main means of accumulation. Importance of thermal stratification. Strategies to enhance the thermal stratification. Quantification of thermal stratification: methods based on energy and exergy balances. Modelling the accumulation system.

Specific objectives:
Description of thermal energy storage systems for heat sensitive.
Introduce the students to the modeling of these systems.

Related activities:
-Lectures or conferences
-Interactive classes
-Oriented theoretical-practical works
-Project, activity or work of reduced scope
-Project, activity or work of broader scope

Related competencies :
CEMT-6. Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage and use of electric energy.
CEMT-5. Employ technical and economic criteria to select the most appropriate thermal equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technological applications in the production, transportation, distribution, storage and use of thermal energy.
CEMT-7. Analyse the performance of equipment and facilities in operation to carry out a diagnostic assessment of the use system and establish measures to improve their energy efficiency.

Full-or-part-time: 17h
Laboratory classes: 4h
Guided activities: 2h
Self study : 11h

Latent heat storage

Description:
Selection of phase change materials depending on the application. Types of storage systems by change of phase. Modeling of phase change systems.

Specific objectives:
Description of thermal energy storage systems by latent heat.
Introduce students to the modeling of these systems.

Related activities:
-Lectures or conferences
-Interactive classes
-Oriented theoretical-practical works
-Project, activity or work of reduced scope
-Project, activity or work of broader scope

Related competencies :
CEMT-6. Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage and use of electric energy.
CEMT-5. Employ technical and economic criteria to select the most appropriate thermal equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technological applications in the production, transportation, distribution, storage and use of thermal energy.
CEMT-7. Analyse the performance of equipment and facilities in operation to carry out a diagnostic assessment of the use system and establish measures to improve their energy efficiency.

Full-or-part-time: 19h
Laboratory classes: 4h
Guided activities: 2h
Self study : 13h

Thermal Storage Systems in concentrated solar power plants

Description:
Importance of energy storage in solar-thermal plants. taxonomy of the storage systems. Main storage media: advantages and disadvantages. Thermal energy storage system on the plant layout. Cost of accumulation system.

Specific objectives:
Introduce the student into the different technologies which might be used in CSP for thermal energy storage and the role of thermal energy storage
Know the different possibilities of operation of a storage system in a CSP plant
Introduce in the analysis of the cost of the system and its impact in the LCOE

Related activities:
-Lectures or conferences
-Interactive classes
-Oriented theoretical-practical works
-Project, activity or work of reduced scope
-Project, activity or work of broader scope

Related competencies :
CEMT-6. Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage and use of electric energy.
CEMT-5. Employ technical and economic criteria to select the most appropriate thermal equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technological applications in the production, transportation, distribution, storage and use of thermal energy.

Full-or-part-time: 16h
Laboratory classes: 4h
Guided activities: 1h
Self study : 11h

Thermo-chemical heat storage

Description:
Principle of operation. Reactive couples. Applications: energy storage in buildings, adsorption and absorption cooling. Developments in progress. Technological aspects.

Specific objectives:
Introduction to the physical principle of sorption systems.
Description of existing technologies.

Related activities:
-Lectures or conferences
-Interactive classes
-Oriented theoretical-practical works
-Project, activity or work of reduced scope
-Project, activity or work of broader scope

Related competencies :
CEMT-6. Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage and use of electric energy.
CEMT-5. Employ technical and economic criteria to select the most appropriate thermal equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technological applications in the production, transportation, distribution, storage and use of thermal energy.
CEMT-7. Analyse the performance of equipment and facilities in operation to carry out a diagnostic assessment of the use system and establish measures to improve their energy efficiency.

Full-or-part-time: 15h
Theory classes: 10h
Laboratory classes: 4h
Guided activities: 1h

Electro-chemical heat storage

Description:
Fuel cells: theoretical basis. Operational fuel cells. Technological development of different types of batteries.

Specific objectives:
Introduce the student into the technology of fuel cells.
Description of existing technologies.

Related activities:
-Lectures or conferences
-Interactive classes
-Oriented theoretical-practical works
-Project, activity or work of reduced scope
-Project, activity or work of broader scope

Related competencies :
CEMT-6. Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage and use of electric energy.
CEMT-5. Employ technical and economic criteria to select the most appropriate thermal equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technological applications in the production, transportation, distribution, storage and use of thermal energy.

Full-or-part-time: 21h 30m
Laboratory classes: 6h
Guided activities: 2h 30m
Self study : 13h

Hydrogen, a vector of clean energy

Description:
Obtention and storage of hydrogen. Processing of fuels used in different types of batteries. Conventional and non-conventional methods.

Specific objectives:
Description of how to obtain and store hydrogen.
Description of fuels used in different types of batteries.

Related activities:
-Lectures or conferences
-Interactive classes
-Oriented theoretical-practical works
-Project, activity or work of reduced scope
-Project, activity or work of broader scope

Related competencies :
CEMT-6. Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage and use of electric energy.
CEMT-5. Employ technical and economic criteria to select the most appropriate thermal equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technological applications in the production, transportation, distribution, storage and use of thermal energy.

Full-or-part-time: 16h 30m
Laboratory classes: 4h
Guided activities: 1h 30m
Self study : 11h

ACTIVITIES

lectures and theoretical classes

Description:
The content of the course is taught following an expository and participative model. The material is organized into different groups according to the content areas of knowledge of the subject.

Specific objectives:
At the end of this activity, students should be able to master the knowledge, consolidate and apply them correctly to various technical problems. Moreover, being a subject techno applied the lectures should serve as a complement to other technical subjects related to the field heat as Refrigeration and Solar Heat Engines.

Material:
Recommended bibliography. Slides of the course

Delivery:
This activity is evaluated in conjunction with activity 2 (problems) via assessment exercises and tests of knowledge.

Full-or-part-time: 20h
Self study: 5h
Laboratory classes: 15h

participative classes

Description:
During these activities, problems and exercises will be conducted using a participatory model class. On each topic, there will be some problems in class so that students can acquire the necessary methodology to carry out their resolution: simplifying assumptions, numerical resolution, discussion of the results.

Specific objectives:
At the end of this activity, students should be able to apply their theoretical knowledge to solve different kinds of problems. Given the methodology the student should be able to:
1- Understand and analyze the problem statement.
2 - Set up and develop a methodology for the resolution of the problem
3 - Solve the problem with a suitable resolution algorithm.
4. - Critically interpret the results.

Material:
Basic and complementary bibliography. Teacher slides

Delivery:
This activity is evaluated in conjunction with activity 1 (theory) via assessment exercises and tests of knowledge.

Related competencies :
CEMT-7. Analyse the performance of equipment and facilities in operation to carry out a diagnostic assessment of the use system and establish measures to improve their energy efficiency.
CEMT-6. Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage and use of electric energy.

Full-or-part-time: 20h
Self study: 5h
Laboratory classes: 15h

Oriented theoretical-practical works

Description:
The works consist of solving small problems, which the basic data can be both from the results of a laboratory or proposed by the professor. The structure to be followed:
-Set up of the practice follwing the guidelines given via the professor notes.
-The students will be organised in small groups of 2-3 students and the maximum duration of the activity will be 2 hours.
- Results and discussion
-Completion of a report on the results carried out consideringf the questions posed by the professor and the conclusions drawn. This report will be evaluated together with the completion of the practice.

Specific objectives:
Consolidate the knowledge acquired in theory and practice classes.

Material:
Bibliography and professor notes

Delivery:
Report on the results

Related competencies :
CEMT-7. Analyse the performance of equipment and facilities in operation to carry out a diagnostic assessment of the use system and establish measures to improve their energy efficiency.

Full-or-part-time: 17h
Self study: 5h
Guided activities: 4h 30m
Laboratory classes: 7h 30m

Reduced scope work

Description:
To solve complex problems based on situations posed by the teacher.

Specific objectives:
Consolidate the knowledge acquired in theory and practice classes.

Material:
Bibliography and professor notes

Delivery:
Report on the results

Related competencies :
CEMT-6. Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage and use of electric energy.
CEMT-7. Analyse the performance of equipment and facilities in operation to carry out a diagnostic assessment of the use system and establish measures to improve their energy efficiency.

Full-or-part-time: 25h
Self study: 25h

Broader scope work

Description:
The student will deepen into a subject and will solve a problem in which there must be necessary to apply different concepts acquired in the course. It is expected that the student is capable of using the different methodologies taught in class in order to accomplish the work.

Specific objectives:
Expand and consolidate the knowledge acquired in theory and practice classes.

Delivery:
Report on the results

Related competencies :
CEMT-7. Analyse the performance of equipment and facilities in operation to carry out a diagnostic assessment of the use system and establish measures to improve their energy efficiency.
CEMT-6. Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage and use of electric energy.
CEMT-5. Employ technical and economic criteria to select the most appropriate thermal equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technological applications in the production, transportation, distribution, storage and use of thermal energy.

Full-or-part-time: 40h
Self study: 40h

Assessment exams

Description:
Theoretical and practice exercises on the different subjects of the course will be assessed

Specific objectives:
Assess the acquired knowledge throughout the course

Material:
Written questionary

Delivery:
The posed qüestions and their answers on the different topics will be handed in to the professor at the end of the exam

Related competencies :
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CEMT-6. Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage and use of electric energy.

Full-or-part-time: 3h
Guided activities: 3h

GRADING SYSTEM

-Final exam (PE): 50%
-Assessment exercises (individually or in small groups) (TR): 40%
-Attendance and participation in classes and laboratories (AP): 5%
-Quality and performance of the work in groups (TG): 5%

During fall semester of the 2020-2021 academic year, and as a result of the health crisis due to Covid19, the qualification method will be:

There will be two assessments exercises to be developed along the course, an online lab and a class final work.
The final grade will be obtained from the continuous evaluation following the formula:
final mark = 0.4(assessment_1 + assessment_2)/2 + 0.2 x online_lab + 0.25 class_final_work + 0.15 x presentation class final work

The final grade will be conditioned to the presentation and oral discussion with the teachers of the work done.

EXAMINATION RULES.

- Final exam (PE): There will be a final exam for the course. Students must complete both theoretical questions and problems related to theoretical and practical content of the course. Reviews and / or complaints regarding exams will be conducted in accordance with the dates and times established in the academic calendar.

- Assessment exercises (TR): Students must follow the instructions explained in class and contained in the work file that will be proposed to the students. As a result of these activities, the student must submit a report (preferably in pdf format) to the teacher, within the deadline fixed for each activity. The assessment will involve both its realization as a possible defense.

-Attendance and participation in classes and laboratories (AP): Laboratory practices are assessed both during the development of the lab and by accomplishing a practical exercises proposed; The report resulting from the lab will be handed in to the professor following the instructions given in class. The assessment will involve both practical realization, as a possible defense.

- Quality and performance of group work (TG): Practices and class exercises will be assessed individually or in small groups by means of their oral defense if necessary.

BIBLIOGRAPHY

Basic:

- Roosa, Stephan A., Doty, Steve, Turner, Wayne C. Energy management handbook [on line]. 9th ed. Gistrup: River, 2020 [Consultation: 27/11/2024]. Available on: https://www-taylorfrancis-com.recursos.biblioteca.upc.edu/books/edit/10.1201/9781003151364/energy-management-handbook-steve-doty-wayne-turner-stephan-roosa. ISBN 9788770222655.
- Goswami, D. Yogi ; Frank Kreith. Energy conversion. 2nd ed. Boca Raton, FL: CRC Press, 2017. ISBN 9781466584822.
- Eastop, T. D; Croft, D. R. Energy efficiency : for engineers and technologists. Harlow, Essex, England : New York: Longman Scientific & Technical, 1990. ISBN 047021645X.
- Winter, C.-J; Sizmann, Rudolf L; Vant-Hull, Lorin L. Solar power plants : fundamentals, technology, systems, economics. Berlin [etc.]: Springer-Verlag, cop. 1991. ISBN 3540188975.
- Dinçer, Ibrahim ; Rosen, Marc. Thermal energy storage : systems and applications [on line]. 3rd ed. Hoboken: Wiley, 2021 [Consultation: 02/12/2024]. Available on: https://onlinelibrary-wiley-com.recursos.biblioteca.upc.edu/doi/book/10.1002/9781119713173. ISBN 9781119713173.
- Herold, Keith E. [et al.]. Absorption chillers and heat pumps [on line]. 2 nd ed. Bosa Roca, US: CRC Press, 2016 [Consultation: 12/06/2025]. Available on: https://ebookcentral-proquest-com.recursos.biblioteca.upc.edu/lib/upcatalunya-ebooks/detail.action?pq-origsite=primo&docID=4497372. ISBN 9781498714358.
- Kordesch, Karl; Simader, Günter. Fuel cells and their applications [on line]. Weinheim [etc.]: VCH, 2018 [Consultation: 23/10/2025]. Available on: https://onlinelibrary-wiley-com.recursos.biblioteca.upc.edu/doi/epub/10.1002/9781118706992. ISBN 9781118706992.

Complementary:

- Nield, Donald A.; Bejan, Adrian. Convection in porous media [on line]. 5th ed.. Cham: Springer, 2017 [Consultation: 19/02/2025]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/978-3-319-49562-0. ISBN 3319495623.
- Duffie, J. A; Beckman, W. A. Solar engineering of thermal processes [on line]. 5th ed. Hoboken: Wiley, 2020 [Consultation: 02/12/2024]. Available on: https://onlinelibrary-wiley-com.recursos.biblioteca.upc.edu/doi/book/10.1002/9781119540328. ISBN 9781119540328.
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- Bogart, Marcel. Ammonia absorption refrigeration in industrial processes. Houston [etc.]: Gulf Publishing, 1981. ISBN 0872010279.
- Dicks, Andrew ; Rand, David A.J.. Fuel cell systems explained [on line]. 3rd ed. Hoboken: Wiley, 2018 [Consultation: 20/10/2025]. Available on: https://onlinelibrary-wiley-com.recursos.biblioteca.upc.edu/doi/book/10.1002/9781118706992. ISBN 9781118706992.

RESOURCES

Audiovisual material:

- Professor slides. Course slides

Computer material:

- Professor notes. Professor notes