MODULE INFORMATION SHEET

Name of Module Unit	**Energy Systems Modelling and Optimization**
Name in polish language	Modelowanie i optymalizacja systemów energetycznych
Module type	compulsory / ~~elective~~
Form of studying	full-time day courses
Level of study	graduate course (M.Sc. level)
Type of study (for extra-mural courses)	-
Programme	Environmental Engineering
Speciality	Environment Protection Engineering
Responsible department	Department of Heating and Gas Systems
Responsible person	Ferdinand Uilhoorn

Semester	Lectures(E)	Tutorials	Laboratory	Computer Exercises	Projects	ECTS
4	30			15		3

Learning outcomes (knowledge, skills, competences)

The aim of this course is to recognize, formulate and able to solve optimization problems (continuous, discrete, mixed, constrained, unconstrained, convex, non-convex, single objective and multi-objective) with a focus, but not limited to, energy system applications.

Prerequisites

Basic knowledge in mathematics (multivariable calculus, linear algebra), thermodynamics, fluid mechanics, and heat transfer. Programming in Matlab.

Rules for integrated grade setting

Final exam 60% and project assignment 40%.

Recommended readings

- C. Audet and W. Warren. Derivative-Free and Blackbox Optimization, Springer, 2017.
- A. D. Belegundu, T. R. Chandrupatla. Optimization Concepts and Applications in Engineering. Prentice Hall, 1999.
- S. Boyd and L. Vandenberghe. Convex Optimization. Cambridge University Press, 2004.
- E. K. P. Chong and S. H. Żak. An Introduction to Optimization. Wiley, Second edition, 2001.
- S. Dasgupta, C. H. Papadimitriou, and U. V. Vazirani. Algorithms. McGraw-Hill, 2006.
- Deb K. Multi-Objective Optimization using Evolutionary Algorithms, 2004.
- P. E. Gill, W. Murray, and M.H. Wright. Practical Optimization. Academic Press, 1981.
- D. M. Himmelblau and T. F. Edgar. Optimization of Chemical Processes. McGraw-Hill, 2001
- Ibrahim D., Marc A. R., Pouria A. Optimization of Energy Systems, John Wiley & Sons, 2017.
- Knoph, C. F. Modeling, Analysis and Optimization of Process and Energy Systems, John Wiley & Sons, 2012.
- J. Nocedal, S. J. Wright. Numerical Optimization. Springer, 2nd edition, 2006.

Contents of lectures (syllabus)

	Topics	**Time** (hrs.)	**Scope** (S / Ex)
1	Introduction. Mathematical preliminaries (convexity, convex sets and functions, conserving convexity). Examples (European gas market, Gas turbine power plant, hybrid solar-wind system, unit commitment problem, two stage compressor station). Notions of minimizers (Weierstrass extreme value theorem, first- and second-order conditions, local (strict) minimum, global (strict) minimum, stationary points, critical points, definiteness). Convexity, concavity, and global optima.	5	S
2	Linear programming. Formulations. Duality. Geometry of LP and optimality of vertices. Simplex method. Issues in Simplex (starting vertex, degeneracy, unboundedness). Running time. Examples (transportation problem. maximum flow problem, solar array farm).	3	S
3	Integer programming. Related problems (zero-one, mixed integer). Algorithmic complexity (Big *O*-notation, P, NP, NP-complete, NP-Hard problems). Formulation "tricks" for logical constraints in IP. Complete enumeration, Branch-and-Bound, Branch-and-Cut. Examples (traveling salesman problem, classical Knapsack problem, efficient energy consumption in smart grids).	3	S
4	Univariate unconstrained minimization. Optimality conditions (necessary and sufficient conditions). Root finding and minimization. Convergence rate. Line-search methods (Fibonacci method, Golden section method, Bisection method, Secant method, Newton's method). Armijo, Goldstein and Wolf conditions.	4	S
5	Unconstrained gradient-based optimization. Steepest descent method. Conjugate Gradient method. Newton's method. Modified Newton's method. Quasi-Newton methods. Levenberg-Marquardt modification.	4	S
6	Handling constraints. Lagrangian function. Karush-Kuhn-Tucker conditions. Penalty and Barrier methods. Sequential Quadratic Programming.	4	S
7	Derivative-free and Blackbox optimization. Popular Heuristic Methods (Nelder-Mead, Genetic algorithms). Direct search method (Mesh Adaptive Direct Search). Examples (A district energy system for controlling energy supply and demand, optimize design and stages of a jet engine, optimal sensor location).	4	S
8	Multi-objective optimization. Classical methods (Weighted sum method, ε-constraint method, weighted metric method). Evolutionary algorithms. BiMADS/MultiMADS. Examples.	3	S
	Total	**30**	**hours**

S – topics listed in the legal study programme standards from 12.07.2007
Ex – extended topics

Lecturers

Ferdinand Uilhoorn

Assessment method

Exam

Contents of computer exercises

	Topics	Time (hrs.)	Scope (S / Ex)
	• Solving a concrete energy design optimization problem (e.g., a boiler-turbine system, a gas transmission system, unit commitment problem or own energy system design problem) • Conducting exercises with the aim to recognize and solve different types of optimization problems, i.e., continuous, discrete, mixed, constrained, unconstrained, convex, non-convex, single objective and multi-objective.	15	S
	Total	**15**	**hours**

S – topics listed in the legal study programme standards from 12.07.2007
Ex – extended topics

Persons responsible for computer exercises

Ferdinand Uilhoorn

Assessment method for computer exercises

- A final report that contains an executive summary, an introduction, problem description, optimization method, data, results, and conclusion. The report will be graded according to organization, content, analysis, and interpretation.
- Completion of the computer exercises.