

## UČNI NAČRT PREDMETA/COURSE SYLLABUS

**Predmet:** Hladilna tehnika in toplotne črpalke - PAP

**Course title:** REFRIGERATION AND HEAT PUMPS - PAP

**Članica nosilka/UL Member:** UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri
Strojništvo - projektno aplikativni program, prva stopnja, visokošolski strokovni	Procesno strojništvo (smer)	2. letnik	2. semester

**Univerzitetna koda predmeta/University course code:** 0563383

**Koda učne enote na članici/UL Member course code:** 3036-V

Predavanja	Seminar	Vaje	Klinične vaje	Druge oblike študija	Samostojno delo	ECTS
30		30			40	4

**Nosilec predmeta/Lecturer:** Andrej Kitanovski

**Vrsta predmeta/Course type:** Izbirni strokovni predmet /Elective specialised course

**Jeziki/Languages:**

Predavanja/Lectures: Slovenščina

Vaje/Tutorial: Slovenščina

**Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:**

**Prerequisites:**

Izpolnjevanje pogojev za vpis v Visokošolski strokovni študijski program I. stopnje Strojništvo - Projektno aplikativni program.

Meeting the enrollment conditions for the MECHANICAL ENGINEERING - Project Oriented Applied Programme.

**Vsebina:**

**Content (Syllabus outline):**

1. Uvod, zgodovinski pregled, osnovne definicije.
2. Termodinamika osnovnih hladilnih krožnih procesov:
  - ☐ Osnovne definicije;
  - ☐ Krožni procesi glede na vrsto hladiva;
  - ☐ Večstopenjski in kaskadni sistemi hlajenja;
  - ☐ Hladilno število;
  - ☐ Grelno število in Letno grelna število;
  - ☐ Eksergijski izkoristek hladilnih naprav in toplotnih črpalk.
3. Parno-kompresijsko hlajenje in toplotne črpalke 1:

1. Introduction, historical overview, basic definitions.
2. Thermodynamics of basic refrigeration cycles:
  - ☐ Basic definitions;
  - ☐ Refrigerants in refrigeration cycles;
  - ☐ Multi-stage and cascade refrigeration systems;
  - ☐ The refrigeration coefficient of performance;
  - ☐ The heat pump coefficient of performance and seasonal heating performance;
  - ☐ Exergy efficiency of refrigeration devices and heat pumps.

<p>☒ Vrste parno-kompresijskih hladilnih naprav in toplotnih črpalk;</p> <p>☒ Termodinamika parno-kompresijskih hladilnih procesov;</p> <p>☒ Hladiva, vrste in lastnosti hladiv, vplivi na okolje, vplivi na učinkovitost delovanja naprav.</p> <p>4. Parno-kompresijsko hlajenje in toplotne črpalke 2:</p> <p>☒ Osnovne komponente parno-kompresijskih naprav;</p> <p>☒ Dodatne komponente in posebnosti;</p> <p>☒ Dimenzioniranje posamezne komponente.</p> <p>5. Parno-kompresijsko hlajenje in toplotne črpalke 3:</p> <p>☒ Ukrepi za izboljšave energijske učinkovitosti;</p> <p>☒ Ukrepi za izboljšave okoljske sprejemljivosti;</p> <p>☒ Načrtovanje, analiza in dimenzioniranje parno-kompresijskih naprav;</p> <p>☒ Delovanje parno-kompresijskih naprav in obratovalne lastnosti.</p> <p>6. Sorpcijsko hlajenje in toplotne črpalke:</p> <p>☒ Vrste sorpcijskih hladilnih naprav in toplotnih črpalk;</p> <p>☒ Termodinamika sorpcijskih hladilnih procesov;</p> <p>☒ Hladiva, vrste in lastnosti hladiv, vplivi na okolje, vplivi na učinkovitost delovanja naprav.</p> <p>7. Absorpcijsko hlajenje in toplotne črpalke:</p> <p>☒ Osnovne komponente absorpcijskih hladilnih naprav;</p> <p>☒ Analiza in dimenzioniranje absorpcijskih hladilnih naprav;</p> <p>☒ Delovanje absorpcijskih hladilnih naprav in obratovalne lastnosti.</p> <p>8. Hladilni procesi s plini:</p> <p>☒ Predstavitev in termodinamika plinskih hladilnih procesov;</p> <p>☒ Klasični Braytonov plinski hladilni proces, delovanje in komponente;</p> <p>☒ Joule-Thomsonov hladilni proces, delovanje in komponente.</p> <p>9. Dimenzioniranje plinskih hladilnih sistemov:</p> <p>☒ Dimenzioniranje naprav z Braytonovim hladilnim procesom;</p> <p>☒ Dimenzioniranje naprav za izkoriščanje Joule-Thomsonovega procesa;</p> <p>☒ Dimenzioniranje vrtnične cevi;</p> <p>☒ Delovanje in obratovalne lastnosti.</p> <p>10. Peltier hladilne naprave in toplotne črpalke:</p> <p>☒ Opis delovanja in preračun učinkovitosti;</p> <p>☒ Materiali;</p> <p>☒ Načrtovanje, analiza in dimenzioniranje Peltier hladilnih naprav;</p> <p>☒ Delovanje in obratovalne lastnosti.</p> <p>11. Aplikacije hlajenja:</p> <p>☒ Hlajenje in zamrzovanje hrane;</p>	<p>3. Vapour-compression refrigeration and heat pumping 1:</p> <p>☒ Types of vapour compression refrigerators and heat pumps;</p> <p>☒ Thermodynamics of vapour-compression refrigeration processes;</p> <p>☒ Refrigerants, types, properties, environmental aspects, influential parameters on the efficiency of devices.</p> <p>4. Vapour-compression refrigeration and heat pumping 2:</p> <p>☒ Basic components of vapour-compression devices;</p> <p>☒ Additional components and their specifics;</p> <p>☒ Dimensioning of components.</p> <p>5. Vapour-compression refrigeration and heat pumping 3:</p> <p>☒ Measures for improvement of energy efficiency;</p> <p>☒ Measures for improvement of environmental aspects;</p> <p>☒ Planning, analysis and dimensioning of vapor-compression devices;</p> <p>☒ Operation of vapour-compression devices and their working characteristics.</p> <p>6. Sorption refrigeration and heat pumping:</p> <p>☒ Types of sorption refrigerators and heat pumps;</p> <p>☒ Thermodynamic of sorption refrigeration processes;</p> <p>☒ Refrigerants, types and properties, environmental impact, influence on the efficiency of operation.</p> <p>7. Absorption refrigerators and heat pumps:</p> <p>☒ Basic components of absorption refrigerators;</p> <p>☒ Analysis and dimensioning of absorption refrigerators;</p> <p>☒ Operation of absorption refrigerators and their working features.</p> <p>8. Gas refrigeration:</p> <p>☒ Introduction and thermodynamics of gas refrigeration cycles;</p> <p>☒ Classical Brayton gas refrigeration cycle, operation and components;</p> <p>☒ Joule-Thomson refrigeration process, operation and components.</p> <p>9. Dimensioning of gas refrigeration cycles:</p> <p>☒ Dimensioning of devices with Brayton refrigeration cycle;</p> <p>☒ Dimensioning of devices for Joule-Thomson process;</p> <p>☒ Operation and working features.</p> <p>10. Peltier refrigerators and heat pumps:</p> <p>☒ Principles of operation and energy efficiency analysis;</p> <p>☒ Materials;</p> <p>☒ Planning, analysis and dimensioning of Peltier refrigeration devices;</p> <p>☒ Operation and working features.</p>
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<p>☒ Industrijsko hlajenje;</p> <p>☒ Hlajenje v blagovnicah;</p> <p>☒ Hlajenje pri transportu;</p> <p>☒ Elektronika;</p> <p>☒ Nizke temperature;</p> <p>☒ Medicina in ostale posebne aplikacije;</p> <p>12. Dimenzioniranje hladilnic za shranjevanje hrane pri nizkih temperaturah:</p> <p>☒ Karakteristike tipičnih produktov za hlajenje in zamrzovanje;</p> <p>☒ Vzdrževanje temperature in vlage;</p> <p>☒ Parametri dimenzioniranja in metode.</p> <p>13. Dimenzioniranje manjših hladilnih naprav za profesionalne in gospodinjske aparate:</p> <p>☒ Karakteristike in zahteve tipičnih produktov za hlajenje in zamrzovanje;</p> <p>☒ Vzdrževanje temperature in vlage;</p> <p>☒ Parametri dimenzioniranja in metode.</p> <p>14. Dimenzioniranje večjih hladilnih naprav:</p> <p>☒ Karakteristike in zahteve večjih sistemov;</p> <p>☒ Izbira primerne vrste hladilne naprave glede na zahtevane parametre, okoljske značilnosti in zahteve, razpoložljivost energentov;</p> <p>☒ Parametri dimenzioniranja in metode.</p> <p>15. Aplikacije in dimenzioniranje toplotnih črpalk:</p> <p>☒ Vrste uporabe in zahteve obratovalnih parametrov;</p> <p>☒ Preračun toplotnih črpalk zemlja-voda z vertikalnimi in horizontalnimi kolektorji;</p> <p>☒ Preračun toplotnih črpalk voda-voda;</p> <p>☒ Preračun toplotnih črpalk zrak-voda;</p> <p>☒ Izbira komponent sistema in energijska analiza.</p>	<p>11. Refrigeration applications:</p> <p>☒ Food refrigeration and freezing;</p> <p>☒ Industrial refrigeration;</p> <p>☒ Supermarket refrigeration;</p> <p>☒ Refrigerated transport;</p> <p>☒ Electronics;</p> <p>☒ Low temperatures;</p> <p>☒ Medicine in and other special applications;</p> <p>12. Dimensioning of refrigerated warehouses for freezing:</p> <p>☒ Characteristics of typical products for refrigeration and freezing;</p> <p>☒ Maintaining the temperature and moisture level;</p> <p>☒ Dimensioning parameters and methods.</p> <p>13. Dimensioning of small refrigeration devices for professional and household appliances:</p> <p>☒ Characteristics and requirements for typical refrigeration and freezing products;</p> <p>☒ Maintaining the temperature and moisture level;</p> <p>☒ Dimensioning parameters and methods.</p> <p>14. Dimensioning of large refrigeration or cooling devices:</p> <p>☒ Characteristics and requirements for large systems;</p> <p>☒ The selection of the appropriate refrigeration/cooling device with regard to required parameters, environmental issues, and availability of energy sources;</p> <p>☒ Dimensioning parameters and methods.</p> <p>15. Applications and dimensioning of heat pumps:</p> <p>☒ Types of use and operation parameter requirements;</p> <p>☒ The analysis and dimensioning of ground source heat pump with horizontal collectors;</p> <p>☒ The analysis and dimensioning of water-water heat pumps;</p> <p>☒ The analysis and dimensioning of air-water heat pumps;</p> <p>☒ The selection of system components and energy analysis.</p>
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### Temeljna literatura in viri/Readings:

1. G. F. Hundy et al. All: Refrigeration and Airconditioning, Elsevier, 2008
2. I. Dincer, M. Kanoglu, Refrigeration Systems and Applications, 3rd Edition, 2017
3. Roy J. Dossat, Thomas J. Horan, Principles of Refrigeration, 2001
4. B. Whitman et al, Refrigeration & Air Conditioning Technology, Cengage Learning, 2013
5. A. Poredoš et al: Heat pumps for heating and cooling, University of Ljubljana, 2018
6. 2017 ASHRAE Handbook—Fundamentals
7. 2018 ASHRAE Handbook—Refrigeration
8. Der Kälteanlagenbauer - Set: Band 1: Grundkenntnisse - Band 2: Grundlagen der Kälteanwendung , 2010
9. R. Radermacher, Y. Hwang, Vapor Compression Heat Pumps with Refrigerant Mixtures, CRC Press, 2005,
10. K. E. Herold, R. Radermacher, S. A. Klein, Absorption Chillers and Heat Pumps, 2016
11. R. Wang, L. Wang, J. Wu, Adsorption Refrigeration Technology: Theory and Application, 2014

**Cilji in kompetence:****Cilji:**

1. Pridobiti znanje za obvladovanje načinov zniževanja temperature za:

- hlajenje in zamrzovanje hrane;
- hlajenje zgradb;
- industrijsko hlajenje;
- hlajenje v blagovnicah;
- hlajenje pri transport;
- elektroniko;
- nizke temperature - kriogeniko;
- posebne aplikacije.

1. Pridobiti aplikativna znanja za izvedbo hladilnih procesov v različnih hladilnih napravah in sistemih.

2. Pridobiti aplikativna znanja za izvedbo črpanja toplote v različnih toplotnih črpalkah in sistemih.

3. Pridobiti sposobnosti analize in dimenzioniranja hladilnih naprav in toplotnih črpalk.

4. Pridobiti sposobnosti za industrijski razvoj.

5. Seznaniti se z najnovejšimi dognanji na področju hladilne tehnike in toplotnih črpalk ter implementacijo teh na različnih področjih inženirstva.

Splošne in predmetno-specifične kompetence:

1. S1-PAP, P1-PAP: Sposobnost dimenzioniranja hladilnih naprav in toplotnih črpalk za realno okolje, sposobnost načrtovanja sistemov, ki temeljijo na razumevanju fizikalnih osnov ter vzpostavitvi znanja in izkušenj o delovanju hladilnih naprav in toplotnih črpalk.

2. S6-PAP, P6-PAP: Sposobnost izvesti samostojno in skupinsko projektno delo z drugimi strokovnjaki na področju analize, implementacije in integracije posameznih komponent hladilnih naprav in toplotnih črpalk.

3. S7-PAP, P9-PAP: Sposobnost vodenja manjših projektov ali tudi skupine s področja analize, dimenzioniranja, praktične optimizacije in industrijskega razvoja na področju komponent, naprav in sistemov hladilne tehnike in toplotnih črpalk.

**Objectives and competences:****Objectives:**

1. To obtain knowledge for mastering different principles of refrigeration:

- Food refrigeration and freezing;
- Cooling in buildings;
- Industrial refrigeration;
- Supermarket refrigeration;
- Refrigerated transport;
- Electronics;
- Low temperatures, cryogenics;
- Special applications.

1. To obtain applied knowledge for design of refrigeration processes in different types of refrigeration devices and systems.

2. To obtain applied knowledge for design of heat pump processes in different types of heat pumps and systems.

3. To obtain ability for analysis and dimensioning of refrigeration devices and heat pumps.

4. To obtain abilities for industrial research and developments.

5. To obtain knowledge on newest findings in the field of refrigeration and heat pumping and their implementation in different fields of engineering.

Basic and subject-specific competences:

1. S1-PAP, P1-PAP: The ability for dimensioning refrigeration and heat pump devices for real environment, the ability of system design and planning, which is based on understanding of basic physical principles and gained knowledge and skills about refrigeration and heat pump operation.

2. S6-PAP, P6-PAP: The ability for individual or group project work with other experts in the field of analysis, implementation, and integration of different components of refrigerator or heat pumps.

3. S7-PAP, P9-PAP: The ability for leading small projects or groups from the field of analysis, dimensioning, practical optimization, and industrial development for components, devices and systems for refrigeration and heat pumping.

**Predvideni študijski rezultati:****Znanja:**

Z1: Poglobljeno strokovno teoretično in praktično znanje na področju hladilne tehnike in toplotnih črpalk, podprto s teoretičnim znanjem o procesih in delovanju, ter pristopom k analizi in dimenzioniranju naprav in sistemov.

**Intended learning outcomes:****Knowledge:**

Z1: Expertize in theoretical, and practical knowledge in the field of refrigeration and heat pumping, supported by theoretical knowledge on processes and operations, and with the approach to analysis and dimensioning of devices and systems.

<p><b>Spretnosti:</b></p> <p>S1.2 Pridobljene spretnosti bodo omogočale obvladovanje procesov dimenzioniranja hladilnih naprav in toplotnih črpalk in njihove umestitve v realno okolje ob različnih vplivnih veličinah.</p> <p>S1.3 Sposobnosti analize in optimizacije komponent in obratovalnih karakteristik hladilnih naprav in toplotnih črpalk v različnih pogojih uporabe.</p>	<p><b>Skills:</b></p> <p>S1.2 Obtained skills will enable mastering of processing for dimensioning of refrigeration and heat pump devices and their integration in real environment at different influential conditions.</p> <p>S1.3 Ability for analysis and optimization of components and operation parameters of refrigeration and heat pump devices at different operating conditions.</p>
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**Metode poučevanja in učenja:**

**Learning and teaching methods:**

<p>P1: Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov.</p> <p>P2: Obravnava snovi po urejeni in vnaprej razloženi sistematiki.</p> <p>P3: Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri.</p> <p>P4: Laboratorijske vaje z namenski didaktični pripomočki (parno-kompresijska hladilna naprava; absorpcijska hladilna naprava; toplotna črpalka zrak-voda, voda-voda; magnetokalorična hladilna naprava, Peltier hladilna naprava in Peltier toplotna črpalka).</p> <p>P5: Uporaba študijskega gradiva v obliki (zapiski, e-verzija predstavitve predavanj).</p> <p>P6, P14, P15: Interaktivna predavanja podprta z video vsebinami, on-line prikazi simulacij konkretnih primerov in virtualnih eksperimentov hladilnih naprav in toplotnih črpalk.</p> <p>P8-P9: Skupinsko delo pri reševanju problemov z izdelavo in predstavitvijo aplikativnih seminarskih nalog (vključuje razprave in diskusije, viharjenje možganov, projektno delo).</p>	<p>P1: Auditorial lectures with analysis of selected - for the domain characteristic theoretical and practically useful examples.</p> <p>P2: The use of subject materials by organized and in-advance explained systematics.</p> <p>P3: Auditoria exercises, where the theoretical knowledge is supported with calculation analysis and examples.</p> <p>P4: Laboratory work with dedicated didactical aids (vapour-compression refrigerator, absorption refrigerator, air-water and water-water heat pump, magnetocaloric refrigeration device, Peltier refrigerator and Peltier heat pump).</p> <p>P5: The use of study material in the form (lecture notes, e-vection of lecture presentations).</p> <p>P6, P14, P15: Interactive lectures supported with video material, on-line simulations of particular problems and virtual experiments of refrigeration and heat pump devices.</p> <p>P8-P9: Group work in solving problems with seminary work and its presentation (includes discussions and analysis, brain storming, project work).</p>
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**Načini ocenjevanja:**

**Delež/Weight**

**Assessment:**

Načini ocenjevanja:	Delež/Weight	Assessment:
Teoretične vsebine (predavanja, računske naloge)	50,00 %	Theory (from lectures and exercise problems)
Samostojno/skupinsko delo na vajah	25,00 %	Individual/group work at exercises
Praktični seminar	25,00 %	Practical seminary work

**Reference nosilca/Lecturer's references:**

Andrej Kitanovski:

- KITANOVSKI, Andrej.** A review of magnetic refrigerator and heat pump prototypes built before the year 2010. International journal of refrigeration, ISSN 0140-7007. [Print ed.], Sep. 2010, vol. 33, iss. 6, str. 1029-1060, [COBISS.SI-ID [11326747](#)], [JCR, SNIP, WoS]
- PLAZNIK, Uroš, VRABELJ, Marko, KUTNJAK, Zdravko, MALIČ, Barbara, ROŽIČ, Brigita, POREDOŠ, Alojz,

- KITANOVSKI, Andrej.** Numerical modelling and experimental validation of a regenerative electrocaloric cooler. International journal of refrigeration, ISSN 0140-7007. [Print ed.], Feb. 2019, vol. 98, str. 139-149, [COBISS.SI-ID 31863079], [JCR, SNIP, WoS]
3. PLAZNIK, Uroš, VRABELJ, Marko, KUTNJAK, Zdravko, MALIČ, Barbara, POREDOŠ, Alojz, **KITANOVSKI, Andrej.** Electrocaloric cooling : the importance of electric-energy recovery and heat regeneration. Europhysics letters : EPL, ISSN 0295-5075, 2015, vol. 111, nr. 5, str. 57009-1-57009-6, [COBISS.SI-ID 14221083], [JCR, SNIP, WoS]
  4. **KITANOVSKI, Andrej,** KLINAR, Katja, TOMC, Urban. Magnetocaloric refrigeration and heat pumping : the present, tomorrow, and the future. V: MINEA, Vasile (ur.). ICR 2019 : refrigeration science and technology proceedings, 25th IIR International Congress of Refrigeration, August 24-30, 2019, Montreal, Canada. Paris: International Institute of Refrigeration = Institut International du Froid. 2019, f. 86-107, ilustr. [COBISS.SI-ID [16772891](#)]
  5. POREDOŠ, Primož, LJUBENKO, Andrej, **KITANOVSKI, Andrej,** POREDOŠ, Alojz. Virtual-prototype-based development of household refrigerator-freezer appliances. V: MINEA, Vasile (ur.). ICR 2019 : refrigeration science and technology proceedings, 25th IIR International Congress of Refrigeration, August 24-30, 2019, Montreal, Canada. Paris: International Institute of Refrigeration = Institut International du Froid. 2019, f. 2263-2270, ilustr. [COBISS.SI-ID [16789019](#)]
  6. POREDOŠ, Primož, PLAZNIK, Uroš, **KITANOVSKI, Andrej,** POREDOŠ, Alojz. Razvoj računalniškega dinamičnega modela za hladilne aparate : končno poročilo. Ljubljana: Fakulteta za strojništvo, Laboratorij za hlajenje in daljinsko energetiko, 2016. [54] f., graf. prikazi. [COBISS.SI-ID [14938395](#)]