POLITECNICO
DI TORINO

Dipartimento Energia
"Galileo Ferraris"

Energetics PhD

Energetics
ANNUAL REPORT 2019

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Graphic: Mariapia Martino

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This document contains a series of one-page reports from the students enrolled in the Energetics PhD program at Politecnico di Torino, Italy, including the highlights of their research activity in 2019. The previous editions of the Annual Report can be downloaded from http://dottorato.polito.it/ene/en/documents_and_awards

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Acknowledgments

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CONTENT

First name: Nicolò **LAST NAME**: ABRATE

Topic: Methods for safety and stability analysis of nuclear systems

Course year: 1st **Tutor(s)**: Sandra Dulla, Nicola Pedroni

Academic context

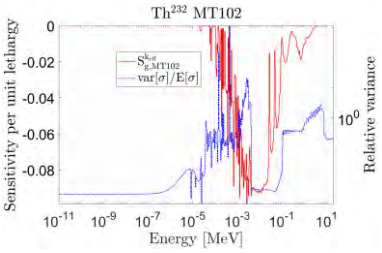
[1] "Assessment of numerical methods for the evaluation of higher-order harmonics in diffusion theory", Abrate, N.; Bruna, G.; Dulla, S.; Ravetto, P., Annals of Nuclear Energy, 128, 455-470, 2019.
[2] D. Xiao, F. Fang, C.C. Pain, I.M. Navon, A parametrized non-intrusive reduced order model and error analysis for general time-dependent nonlinear partial differential equations and its applications, Comput. Methods Appl. Mech. Engrg., 317, 868-889, 2017.
[3] A. Sargeni, K.W. Burn, G.B. Bruna, The impact of heavy reflectors on power distribution perturbations in large PWR reactor cores, Annals of Nuclear Energy, 94, 566-575, 2016.

External collaborations

- Politecnico di Milano

Highlights of the research activity

This PhD research topic, funded within the ESTAMOS project, has the main objective of developing computational methods for the safety assessment of complex systems, focusing on advanced nuclear reactors, like GEN-III+ and GEN-IV designs. The main motivation of this research topic is to provide an integrated approach between the traditional reactor physics numerical methods and some recently developed reduced order models employed to reduce the computational burden associated to the numerical simulations typically required for a safety assessment of nuclear reactors.



Th-232 relative covariance and sensitivity per unit lethargy for radiative capture (MT=102)

Neutronics-related activities have concerned the study of Generalized Perturbation Theory (GPT), which is a standard reactor physics technique that allows the neutron flux reconstruction in presence of localized perturbations using pre-computed sets of eigenfunctions evaluated on a reference, unperturbed configuration. Since the available number of flux harmonics is usually limited, GPT is traditionally adopted as a first order tool for sensitivity analysis and uncertainty quantification (UQ). Therefore, in order to increase the applicability range of GPT, an assessment of numerical techniques able to provide also the higher order flux modes has been carried out. Such evaluation remarked that *Implicitly Restarted Arnoldi* (IRA) is currently the best numerical scheme available for both its numerical efficiency and its non-intrusiveness for implementation in nuclear production codes. The use of IRA raises the interest in higher order GPT, therefore some analytical and numerical tests have been carried out to assess its convergence behaviour. These calculations showed that, for certain sets of perturbation intensity and spatial width in the domain, GPT may miss convergence, leading thus to possible dangerous spurious results.
On a parallel track, in the framework of the European project SAMOFAR, a UQ study concerning the influence of the uncertainty in the nuclear data on main neutronic parameters of the GEN-IV Molten Salt Fast Reactor has been carried out. Using both GPT and a reduced order approach known as XGPT, the uncertainty on the effective multiplication parameter has been estimated for the main nuclides of interest, i.e. Th-232 and U-233.
As regards the safety-related activities, a non-intrusive reduced order model has been selected for core stability monitoring due to its promising features. This method consists in a training phase, when the neutronic model is executed a certain number of times in order to map the parameter space, and in the surrogate model construction, which allows to reproduce, within certain error limits, the results of the original high-fidelity model interpolating between already explored points.
To sum up, the main research activities led in the neutronics field allowed, on one side, to test the behaviour of existing computational techniques to monitor the nuclear reactor core stability, on the other to acquire familiarity with both the physics and the tools employed for the innovative GEN-IV reactors. As far as computational safety is concerned, a promising reduced order method was selected on the basis of some required constraints. The years to come will be devoted to test and integrate GPT and the reduced order model.

First name: Francesco **LAST NAME**: ACCURSO

Topic: Large Bore Gas Combustion Technology Development by Predictive Combustion Model

Course year: 1st **Tutor(s)**: Federico Millo

Academic context

[1] Fogla, N., Bybee, M., Mirzaeian, M., Millo, F. et al., "Development of a K-k-ε Phenomenological Model to Predict In-Cylinder Turbulence," SAE Int. J. Engines 10(2):2017, doi: 10.4271/2017-01-0542.
[2] Millo, F., Boccardo, G., Piano, A., Arnone, L. et al., "Numerical Simulation of the Combustion Process of a High EGR, High Injection Pressure, Heavy Duty Diesel Engine," SAE Technical Paper 2017-24-0009, 2017, doi:10.4271/2017-24-0009.
[3] Walther, H. P., Schlatter, S., Wachtmeister, G., & Boulouchos, K. (2012). Combustion models for lean-burn gas engines with pilot injection. MTZ worldwide, 73(2), 56-63.

External collaborations

- Wärtsilä
- Gamma Technologies LLC
- Powertech Engineering

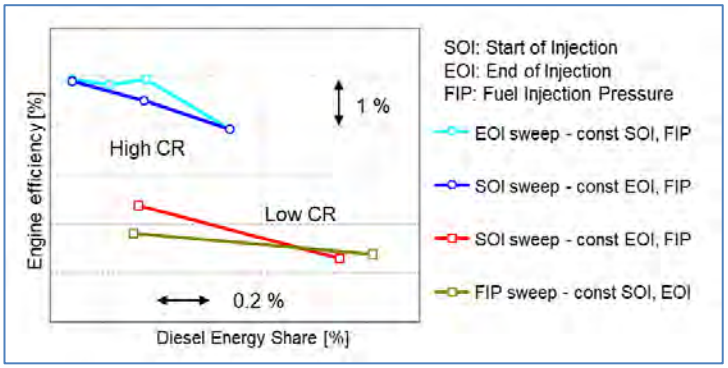
Highlights of the research activity

Natural Gas for marine applications leads to evident benefits in terms of CO_2 and pollutant emissions. However, a step forward from current technologies is mandatory to comply with the increasingly severe emissions targets and the ever more stringent fuel economy market demands. Within such a framework, numerical simulation, relying on predictive combustion models, is fundamental for the investigation of new technologies. In this regard, the research activity concerns indeed the development of a predictive 0D combustion model for large bore dual-fuel engines.

The research activity started with a literature review concerning dual fuel combustion and its modelling. As reported in literature, the combustion of a lean gas-air mixture ignited by a micro-diesel fuel injection remains a not completely understood phenomenon. Optical accessible laboratory engine and 3D-CFD analysis allow to gather a deeper understanding of the physics and of the chemistry involved in the combustion process. I had the opportunity to spent two weeks in Wartsila laboratories (Vaasa, Finland). I took part of an experimental test campaign on a dual fuel engine, collecting several engine data required for my research activity. A laboratory Single Cylinder Engine (SCE) was selected as first application for the dual fuel combustion model development. The analysis of the experimental SCE data showed a strong impact of the pilot diesel specifications on the gas combustion and consequently on the engine performance and emission, even if the diesel energy share is generally lower than 3%.

Firstly, for the combustion model development, a 3D-CFD analysis was carried out, that focuses on the natural gas-air mixture and on the turbulence prior to combustion. The results from the 3D-analysis were used for the correlation of a 0D turbulence model. The 0D turbulence model showed a good agreement with the 3D-CFD results.

The activity proceeded with the development of a 0D combustion model for the pilot diesel fuel. To do so, diesel injection rates have been accurately defined from the injection profiles measured with the Wartsila injection test rig.



Effect of diesel specifications on engine efficiency

First name: Matteo **LAST NAME**: ALBERGHINI

Topic: Thermal management via engineered passive transfer phenomena

Course year: 1st **Tutor(s)**: Pietro Asinari, Eliodoro Chiavazzo, Alberto Tiraferri

Academic context

[1] Woods, J., Pellegrino, J., Kozubal, E., Slayzak, S., & Burch, J. (2009). Modeling of a membrane-based absorption heat pump. Journal of Membrane Science, 337(1-2), 113-124.
[2] Cai, L., Song, A. Y., Li, W., Hsu, P. C., Lin, D., Catrysse, P. B., ... & Xu, J. (2018). Spectrally selective nanocomposite textile for outdoor personal cooling. Advanced Materials, 30(35), 1802152.
[3] Tong, J. K., Huang, X., Boriskina, S. V., Loomis, J., Xu, Y., & Chen, G. (2015). Infrared-transparent visible-opaque fabrics for wearable personal thermal management. ACS Photonics, 2(6), 769-778.

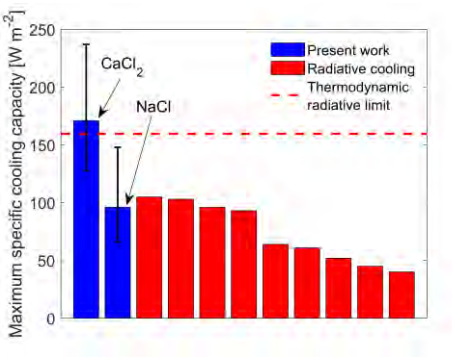
External collaborations

- Massachusetts Institute of Technologies (MIT)
- Istituto Nazionale di Ricerca Metrologica (INRIM)

Highlights of the research activity

Space cooling in buildings is foreseen to rise due to an increasing thermal comfort demand worldwide, and this calls for cost effective, scalable and sustainable cooling technologies. The research activity aims to address the related environmental issue by investigating the potential of novel passive cooling technologies.

For this purpose, a proof-of concept prototype is built and tested using cheap and off-the-shelf materials. The device only relies on passive phenomena: the net cooling load is developed by the difference in concentration of two aqueous solutions, while the supply and discharge of the working fluids is managed by capillary porous media and pressure gradients. The device is designed to be modular, namely a vertical repetition of identical stages, each of them able to sustain the cooling process. This configuration reduces the thermal losses across each stage, increasing the overall performances of the device.
Comparing the cooling capacity achieved by our 3-stages prototype with those of radiative cooling technologies, we experimentally achieved better performances than state-of-the-art materials, reaching values beyond their thermodynamic limit, namely approximately 170 Wm^{-2} as shown in Figure 1. Furthermore, the performances can be furtherly enhanced by increasing the number of the staked stages or engineering the salt solution employed.
The current work focuses on engineering the capillary porous medium. Enhancing its fluid transport properties is a key factor to increase the maximum number of stackable stages, the evaporation rate, and, thus, the overall performance of the device. For this purpose, polyethylene (PE) microfibers are fabricated and assembled into yarns, which can be woven with specific patterns to create a fabric with tailored wicking parameters.
PE, besides being a cheap and highly-recyclable material, is selected for its outstanding optical properties, which result in radiative cooling by a fine tuning the shape of the fibers (2-3 μm). The synergistic combination of radiative and evaporative cooling allows to envision a new class of single-layered materials for personal thermal management, maximizing their passive cooling properties.



Comparison between the cooling performance obtained by the proposed device when operating with two different dilutions (blue bars) and the theoretical and experimental performances of radiative cooling technologies (red bars, different references). The thermodynamic limit of radiative cooling is reported with a dashed red line

First name: Andrea **LAST NAME**: BERSANO

Topic: Innovative heat removal and transport systems for advanced nuclear reactors

Course year: 3rd **Tutor(s)**: Mario De Salve, Cristina Bertani

Academic context

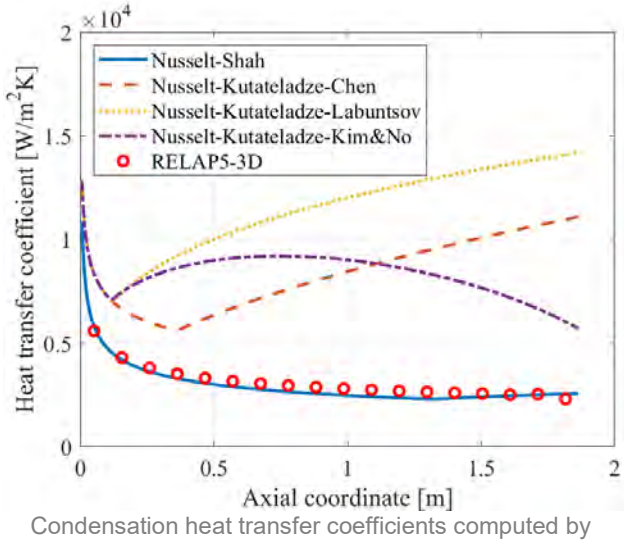
[1] A. Bersano, N. Falcone, C. Bertani, M. De Salve, B. Panella, Conceptual design of a bayonet tube steam generator with heat transfer enhancement using a helical coiled downcomer, Progress in Nuclear Energy, 108, pp. 243-252, 2018.
[2] M. Caramello, M. Gregorini, C. Bertani, M. De Salve, A. Alemberti, B. Panella, Thermal hydraulic analysis of a passively controlled DHR system, Progress in Nuclear Energy, 99, pp. 127-139, 2017.
[3] A. Bersano, N. Falcone, C. Bertani, M. De Salve, F. Mascari, C. Lombardo, Validation of RELAP5-3D thermal-hydraulic code against full-scale PERSEO Test 9, Proceedings of International Congress on Advances in Nuclear Power Plants, 2019.

External collaborations

- ENEA
- SIET

Highlights of the research activity

Passive systems are being implemented or envisaged in the design of several nuclear plants to increase the safety and to reduce the construction cost and time. Their application can reduce the magnitude of potential risks. The research activity deals with the analysis of passive systems, with a particular attention to those systems operating in natural circulation for the removal of the decay heat in accidental conditions.
In the framework of the OECD/NEA/CSNI/WGAMA an open international benchmark hosted by ENEA has been conducted on PERSEO facility available at SIET laboratory in Piacenza (Italy). The thermal-hydraulic code RELAP5-3D has been adopted in the benchmark, and the capabilities and limitations of the code in the prediction of the phenomena typical of this passive system have been highlighted. In particular it has been found that the condensation heat transfer coefficient is significantly underestimated by the code and an alternative correlation has been identified. In parallel, ENEA FSN-SICNUC division has been supported in the preparation of the benchmark results report and other contributions have been prepared for the “Status report on thermal-hydraulic passive systems design and safety assessment” which is being finalized.
An experimental campaign has been conducted on another natural circulation passive systems, the upgraded PROPHET2 facility at Politecnico di Torino, and the results have been analyzed to identify the most relevant phenomena in the system start-up and steady-state phases and the capability of RELAP5-3D to correctly predict them.
Finally, the probabilistic propagation of input uncertainties method has been applied to the natural circulation system PERSEO and to the pressure suppression passive system in an Ingress of Coolant Event in an experimental facility for fusion plants. The objective is to evaluate if this method is applicable to passive systems, if the experimental data could be bounded by the uncertainty bands and to compute the correlations between the selected uncertain input parameters and the most relevant outputs for the operation of the system.



Condensation heat transfer coefficients computed by RELAP5-3D and with alternative correlations

First name: Silvio **LAST NAME**: BRANDI

Topic: Adaptive Control Strategies for improving energy flexibility in buildings

Course year: 1st **Tutor(s)**: Alfonso Capozzoli

Academic context

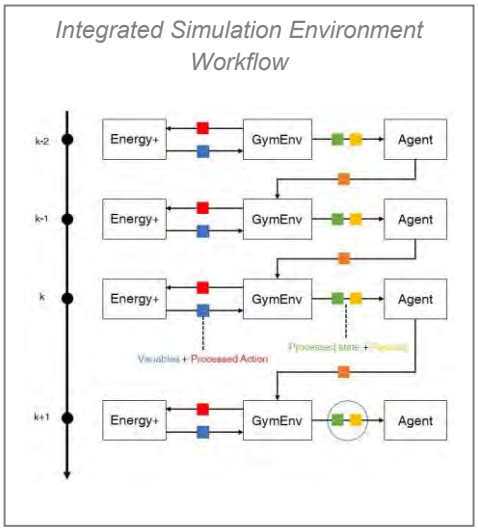
[1] Capozzoli A, Piscitelli M S, Brandi S, Grassi D, Chicco G. Automated load patterns learning and diagnosis for enhancing energy management in smart buildings. Elsevier, Energy 2018; 157:336-352 https://doi.org/10.1016/j.energy.2018.05.127
[2] Vàzquez-Canteli J., Nagy Z. Reinforcement learning for demand response: A review of algorithms and modeling techniques. Elsevier, Applied Energy (2019) 235:1072-1089 https://doi.org/10.1016/j.apenergy.2018.11.002
[3] Zhang Z, Chong A, Pan Y, Zhang C, Poh Lam K. Whole building energy model for HVAC optimal control: A practical framework based on deep reinforcement learning. Elsevier. Energy & Buildings (2019) 199:472:490 https://doi.org/10.1016/j.enbuild.2019.07.029

External collaborations

- Enerbrain s.r.l.
- University of Texas (Austin)

Highlights of the research activity

Adaptive and predictive optimal control provides powerful opportunities for leveraging building properties (e.g. thermal mass, storage, renewable energy sources) to enhance energy flexibility during operation. In analysing the current scientific literature particular attention was devoted to Deep Reinforcement Learning (DRL) control techniques applied to HVAC systems. DRL does not require a model of system dynamics, rather, an agent learns an optimal control policy from past interactions with an environment through a trial and error approach. The main activity carried out during the first-year deals with the development of an integrated simulation environment. In the environment EnergyPlus, is combined with Python, an open-source programming language. Python supports state of the art deep learning libraries such as Tensorflow, Keras and PyTorch. The communication between the two tools is handled through Building Control Virtual Test Bed (BCVTB). Through this infrastructure a dynamic exchange of data with EnergyPlus can be performed while simulation is running: at each time step EnergyPlus receives control inputs from python code and sends simulation output back to it in order to determine the following control action. This configuration allows the user to simulate the effect on the building system of any controller (e.g. rule based, MPC, DRL) overcoming EnergyPlus limitations in implementing advanced control logics. In order to create a standard reinforcement learning environment, EnergyPlus has been wrapped into an OpenAI gym interface within Python. With the purpose of testing the integrated simulation environment a case study provided by Enerbrain s.r.l. was developed. The case study consists in an office building located in Torino with a surface on 9800 m2 and three separate thermal zones. A monitoring infrastructure developed by Enerbrain collects and stores real time measurements related to energy consumption and indoor temperature, humidity and CO2 concentration for the different thermal zones. A DRL agent was developed to control the position of a three-way mixing valve which fed one of the thermal zones. The objective functions of the control are related to the optimisation of heating energy consumption while maintaining acceptable indoor comfort conditions. Several tests were carried out in order to determine the adaptability of the RL agent to flexible indoor conditions such as variable occupancy schedule and internal setpoint requirements.



First name: Giulio **LAST NAME**: BUFFO

Topic: Carbon capture process based on innovative ionic liquids: experimental assessment and analysis of integrated CO_2 capture and re-utilization pathways

Course year: 1st **Tutor(s)**: Massimo Santarelli, Andrea Lanzini

Academic context

[1] T. E. Akinola, E. Oko, and M. Wang, "Study of CO_2 removal in natural gas process using mixture of ionic liquid and MEA through process simulation", Fuel, vol. 236, no. July 2018, pp. 135–146, 2019.
[2] G. Latini, M. Signorile, V. Crocellà, S. Bocchini, C. F. Pirri, and S. Bordiga, "Unraveling the CO_2 reaction mechanism in bio-based amino-acid ionic liquids by operando ATR-IR spectroscopy" Catal. Today, vol. 336, no. December 2018, pp. 148–160, 2019.
[3] G. Buffo, P. Marocco, D. Ferrero, A. Lanzini, and M. Santarelli, "Power-to-X and Power-to-Power routes" in Solar Hydrogen Production: Processes, Systems and Technologies, Elsevier, 2019, pp. 530–575.

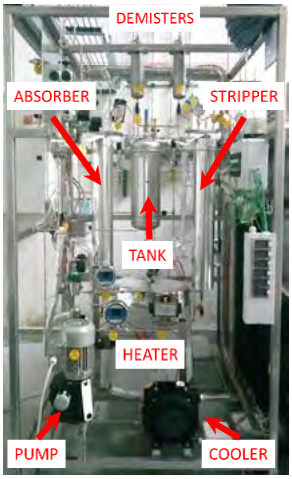
External collaborations

- Istituto Italiano di Tecnologia (IIT)
- Gruppo IREN S.p.A.

Highlights of the research activity

The research investigates a novel process based on ionic liquids for capturing carbon dioxide (CO_2) emitted by the power and industry sectors to enable their progressive decarbonization. The captured CO_2 is reused to produce synthetic fuels integrating and storing renewable electricity. Hence, the analysis is divided in two areas:

- Carbon capture (CC). A model of absorption/desorption CC with state-of-art H_2O/MEA (monoethanolamine, 70/30 $\%_v$) solvent was developed with the process simulator Aspen Plus and validated with literature data. Unlike amine-based solutions, "conventional" ionic liquids (ILs) mainly capture CO_2 through physical absorption with a limited heat duty for solvent regeneration. Hence, the replacement of 30% of water in the reference solvent with [bpy][BF_4] IL results in a reduction of the solvent regeneration heat from 4.38 to 3.31 kJ/g_{CO2} due to lower heat capacity with just a 12% increase of solvent demand. The absorption capacity can be improved by including functional groups that chemically react with CO_2, such as amine groups. Bio-inspired ILs that rely on choline and amino-acids (AAILs) will be synthetized and characterized in collaboration with IIT. Process modeling with these solvents will be supported by the results of tests performed in the prototypal two-column rig (Fig. 1) designed during the 1st year of my PhD and trialed at Environment Park as part of the INFRA-P CO_2 Circle Lab.
- Carbon Utilization (CU). The study focuses on the role of electrolysis for the storage of renewable electricity in the form of hydrogen (Power-to-H_2, PtH_2 scheme) and its combination with captured CO_2 (PtH_2/CO_2-to-X schemes) for the production of added-value commodities for different applications. As an example of PtH_2 concept, a recently submitted work demonstrated the key role (55-70% annual efficiency) of an rSOC (Reversible Solid Oxide Cell) system in supporting the integration of wind energy on a residential microgrid, by providing from 26% to 35% of the local electricity demand and significantly reducing both the power peaks at the interface with the electricity distribution grid and the CO_2 emissions (5-50% less than a reference energy system). As a possible PtH_2/CO_2-to-X extension, an additional option analyzed is the use of part of the H_2 to produce Di-Methyl Ether (DME) with CO_2 captured from biogas obtained from municipal solid wastes: the need for additional H_2 and heat for DME synthesis imply a reduction of system efficiency proportional to DME demand (-9% ca. in case of 2 t/day of DME).



Rig for CC test (work in progress)

First name: Luigi **LAST NAME**: CANDIDO

Topic: Lithium-lead and Tritium Technologies

Course year: 1st **Tutor(s)**: Massimo Zucchetti, Raffaella Testoni

Academic context

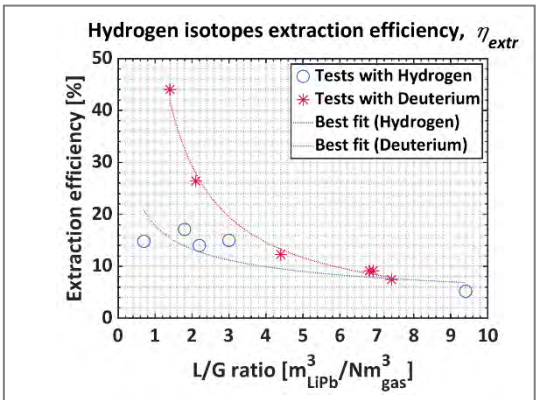
[1] M. Utili, A. Tincani, L. Candido, L. Savoldi, R. Zanino, M. Zucchetti, D. Martelli, A. Venturini. Tritium Extraction from HCLL/WCLL/DCLL PbLi BBs of DEMO and HCLL TBS of ITER. IEEE Transactions of Plasma Science, Volume 47, no. 2, February 2019, Pages 1464-1471.
[2] V. Linek, L. Košek, T. Moucha, F.J. Rejl, M. Kordač, L. Valenz, M. Opletal. The engineering sizing of the packed desorption column of hydrogen isotopes from Pb–17Li eutectic alloy. A rate based model using experimental mass transfer coefficients from a Melodie loop. Fusion Engineering and Design,Volume 89, Issue 11, 2014, Pages 2504-2515.
[3] A. Aiello, A. Ciampichetti, M. Utili, G. Benamati. TRIEX facility: An experimental loop to test tritium extraction systems from lead lithium. Fusion Engineering and Design, Volume 82, Issues 15–24, 2007, Pages 2294-2302.

External collaborations

- Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico (ENEA), Centro Ricerche Brasimone, Camugnano (BO) – Italy.
- Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Madrid – Spain.
- Commissariat à l'énergie atomique et aux énergies alternatives (CEA), Cadarache, Saint-Paul-lez-Durance – France.

Highlights of the research activity

The need of a CO_2 free, sustainable and reliable source of electricity is mandatory to meet the well-established and growing global need of energy, in particular for a baseload power generation to be guaranteed. Under these points of view, fusion energy is one of the few candidate technologies able to meet this goal, aiming to provide fusion electricity to the grid by the middle of the 21st century. The European DEMO, the next-future first demonstration power reactor, will use lithium-lead alloy with the function of tritium breeder, tritium carrier and neutron multiplier, and water at typical PWRs conditions as coolant to remove the heat generated by the D-T reaction in the plasma.



GLC mock-up extraction efficiency as a function of the liquid/gas ratio

My research during the first year of PhD covered several topics linked to fusion technology, with particular regard to the aspects of lithium-lead and tritium technologies. At ENEA Brasimone research centre, an experimental facility named TRIEX-II has been designed and built to test a new technology for tritium extraction from lithium-lead alloy. We developed a Gas/Liquid Contactor (GLC) mock-up, of packed-column type, in order to test and qualify the extraction efficiency of hydrogen isotopes from LiPb, using hydrogen and deuterium to simulate tritium. The mock-up consists in a vessel where the LiPb with H or D solubilized (liquid phase, L) flows from the top in counter-current with respect to a stripping gas constituted by helium or by a mixture of helium and deuterium (gas phase, G). The extraction efficiency, Fig. 1, has been found to be well in agreement with predictive theoretical analyses developed by means of a dedicated COMSOL/Simulink model. The maximum extraction efficiency was 44%, confirming this technology could be considered one of the candidate technologies for DEMO. These works have been presented at the 14th International Symposium on Fusion and Nuclear Technology, ISFNT, held in Budapest, Hungary, in September 2019.

First name: Marco **LAST NAME**: CAVANA

Topic: Gas network modeling for integrated energy infrastructures

Course year: 3nd **Tutor(s)**: Pierluigi Leone, Gianfranco Chicco

Academic context

[1] Cavana M., Leone P., "Biogas blending into the gas grid of a small municipality for the decarbonization of the heating sector". In Biomass and Bioenergy, August 2019;
[2] Cavana M., Leone P., "Towards Renewable Gases Distribution Networks: The Importance of a Transient and Multi-Component Fluid-Dynamic Gas Model". In: 27th EUBCE Proceedings,July 2019;
[3] Chaczykowski, M.et al.,"Gas composition tracking in transient pipeline flow". In: Journal of Natural Gas Science & Engineering, March 2018.

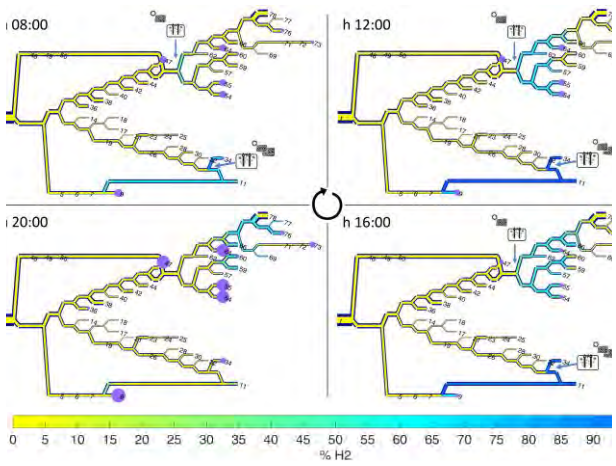
External collaborations

- Snam
- Italgas
- TU-Delft

Highlights of the research activity

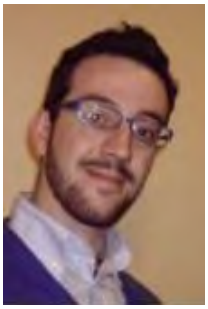
The share of electricity in today's total final energy consumption is around 20%. According to the long-term decarbonization goals, this share will double to 40% by 2050 with the remainder still supplied by "molecules". Thus, the process of decarbonization must pertain also to chemicals, either feedstock or fuels and renewable gases such as biomethane and hydrogen, will play a prominent role.In paticular, the gas industry will have to manage all the issues related with the allowance of unconventional gases within the existing infrastructure. This calls for the need of suitable modelling framework to asses opportunities and criticalities of this transition.

A new gas network model has been developed during the past year. It is based on transient fluid-dynamic equations for the simulations of the pipelines and the natural gas is modeled as a mixture of 21 components by means of the GERG-2008 equation of state. The way the algorithm is structured makes the model flexible to any topological complexity.
The model has been applied to a distribution network of a small rural municipality under different renewable gas injection scenarios:
1) Biomethane injection: the mismatch between constant production and the strong seasonality of resdential gas consumption is critical for gas networks with limited capacity and ends up with a curtailment of produced biomethane. Taking advantage of the transient feature of the model, it is possible to test strategies in order to use the linepack capacity as a storage buffer, based on modulating pressures
2) Hydrogen injection: long-term scenarios consider power-to-hydrogen as a possible option both for the storage of renewable energy and for the decarbonization of the gas sector, by means of hydrogen blendings. Taking advantage of the quality tracking feature of the model, a number of simulations have been performed under solar hydrogen blending scenario. The picture shows the case of a double distributed injection during summertime conditions (i.e. higher production – lower consumption): It is possible to note the strong impact in terms of quality perturbation, the hydrogen diffusion and its persistency once the injection is terminated.



Evolution of H_2 content in the natural gas of a distribution network under multiple blending scenario (summer case)

The results of these activities shows that advanced network modeling is a necessary activity to ease the integration among energy infrastructures based on the creaion of a multi-gas system.



First name: Alessandro **LAST NAME**: CORVAGLIA

Topic: Advanced modelling of lubricated gaps in positive displacement machines

Course year: 1st **Tutor(s)**: Massimo Rundo

Academic context

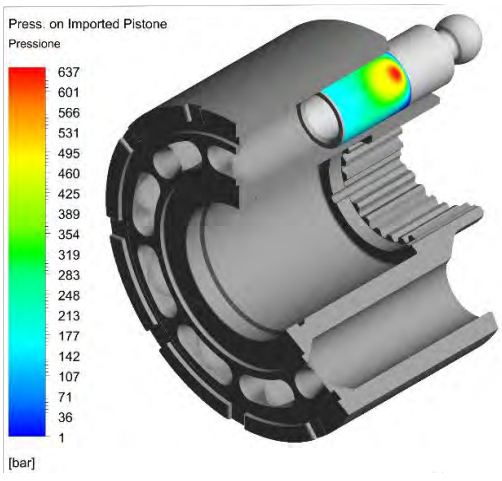
[1] Monika Ivantysynova & Rolf Lasaar (2014) – "An Investigation into Micro- and Macrogeometric Design of Piston/Cylinder Assembly of Swash Plate Machines", International Journal of Fluid Power, 5(1): 23-36.
[2] Matteo Pelosi & Monika Ivantysynova (2012) – "A Geometric Multigrid Solver for the Piston-Cylinder Interface of Axial Piston Machines", Tribology Transactions, 55(2): 163-174.
[3] Stefan Gels & Hubertus Murrenhoff (2010) – "Investigation of Elastic Deformations of Cylinders within the Simulation of Piston-Cylinder-Contacts of Axial Piston Machines", IFK Proceedings 2010, Aachen, Germany.

External collaborations

- Casappa S.p.A.

Highlights of the research activity

A proper design of the functional clearances in fluid power pumps is mandatory to reduce the absorbed energy and to extend the mean time to failure of the component.
The piston-cylinder interface in axial piston pumps is probably the most challenging problem, because the piston cannot be just hydrostatically balanced like other interfaces, due to reciprocating motion.
During this first year, a parametric tool to solve the pressure distribution between the bodies starting from the 2D Navier-Stokes equations with the hypothesis of isothermal fluid flow has been implemented. The fluid domain was discretized with the FVM (Finite Volume Method) in Cartesian coordinates, solving the so called "unwrapped case".
By contrasting different solution algorithms, the Conjugate Gradient Method was chosen being the fastest and the easiest to implement among those ones compared, allowing assessing the leakage flow rate and the viscous friction on the piston with imposed constant tilt.
Even if the manufacturing tolerances are very tight, the piston is able to perform micro-movements inside the bushing (tilting, rotation around its own axis and translation), thus, the underway activity involves the coupling of the resultant pressure forces acting on the piston with the external loads acting on the assembly. With this model, it will be possible to estimate also the piston micro-motions and the equilibrium positions during an entire pumping cycle. The built model is fully parametric and it has been implemented inside the Simcenter Amesim software, through a customized library written in C language.
A parallel topic addressed during the first year of PhD was the assessment of the radial clearance in gerotor pumps starting from CAD profiles. Usually the study of gear machines requires as input the analytic description of the gears profiles and of the port plate. In order to contrast different and/or innovative profiles, the process has been generalized starting from the real CAD component building up the automatic calculation of the chamber volume, its derivative and the radial gap between the teeth with a specific algorithm. This advancement allows to exploit the capability of new CAD optimization design tools without the analytical description of the gears.
The accuracy of this method strongly depends on the number of points: a greater number will result in a more accurate solution, but with a greater computational time.



Pressure distribution in the Piston-Cylinder block interface

First name: Andrea **LAST NAME**: COSTANTINO

Topic: The role of climate control in decreasing the overall energy consumption of intensive livestock houses and greenhouses: insights and opportunities

Course year: 2nd **Tutor(s)**: Enrico Fabrizio, Salvador Calvet Sanz (UPV)

Academic context

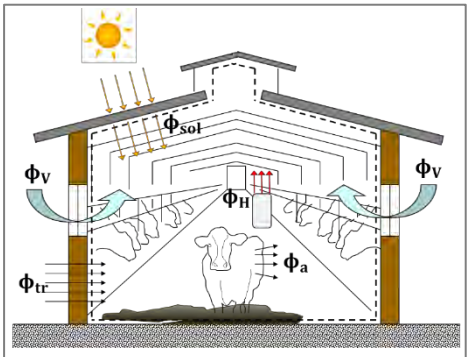
[1] FAO, Energy-Smart Food at FAO: an Overview, FAO, Rome, Italy, 2012.
[2] M.A. Hellickson, J.N. Walker, Ventilation of Agricultural Structures, ASAE Monograph Number 6, American Society of Agricultural Engineers, St. Joseph, Michigan, 1983.
[3] ASHRAE, Environmental Control for Animals and Plants, in: ASHRAE Handbook-HVAC Applications, SI Edition, Atlanta, Georgia, 2007.

External collaborations

- Department of Agricultural, Forest and Food Sciences, Università degli Studi di Torino, Grugliasco (TO), Italy
- Munters Italy S.p.a., Chiusavecchia d'Imperia (IM), Italy
- School of Agricultural Engineering and Environment, Universitat Politècnica de València (UPV), Valéncia, Spain

Highlights of the research activity

Energy consumption in agricultural sector is expected to increase in the coming future. To feed the entire population and to decrease the level of energy intensity, improvements in the food supply chain are needed. Aim of this thesis is to develop a new smart-energy farm concept characterized by high productivity and reduced energy consumption due to climate control in greenhouses and livestock houses.



Terms of the sensible heat balance considered in the developed energy simulation model

The first year of doctorate was characterized by both numerical and experimental approaches. The numerical approach was focused on the definition of robust and reliable energy simulation models (Fig. 1) for these building types, in particular, for broilers and growing-finishing pigs (in collaboration with animal scientists of the University of Turin). The numerical approach concerned also intensive crop production through the development of an energy simulation model for greenhouses (in collaboration with Munters Italy S.p.a.).
During the second year, the developed models were applied to evaluate the influence of the farm management on the energy consumption and to evaluate energy saving strategies. The model for broiler house was used (in collaboration with Universitat Politècnica de València) to assess how the reduction of indoor gas concentrations through ventilation affects the energy consumption for climate control. The results show that to maintain adequate thresholds of gas concentrations the primary energy consumption increases by 13% entailing an extra-cost of 0.02 € per harvested broiler.
The broiler energy model was also used to evaluate the energy consumption for broiler production in different climates across Europe. The study evaluated also the difference in the energy consumption using different envelope types, demonstrating that the increase of the thermal insulation reduces the primary energy consumption also in mild climates, without causing heat stress to the reared animals.
Finally, the energy simulation model for pigs was used to practically apply the methodology for the animal house energy certification scheme previously defined in the framework of the EPAnHaus project. A first draft of this certification was applied to a case study in Cuneo province. This energy certification will be fine-tuned and applied to different case studies during the third year of doctoral activity.

First name: Paolo **LAST NAME**: DE ANGELIS

Topic: Automation and artificial intelligence tools to advance the materials modelling in the energy field

Course year: 1st **Tutor(s)**: Pietro Asinari, Daniele Marchisio, Eliodoro Chiavazzo

Academic context

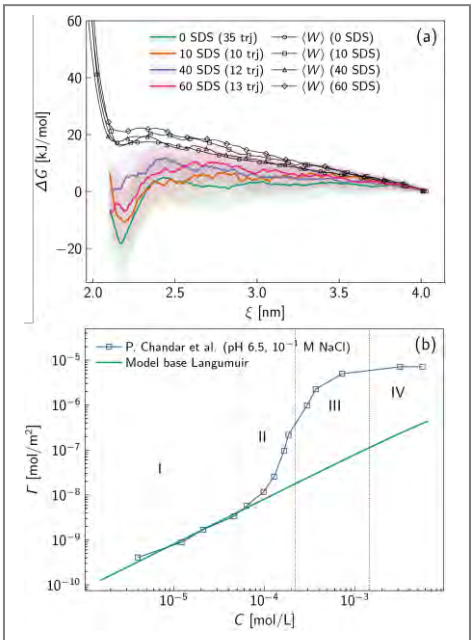
[1] De Angelis, P., Cardellini, A. and Asinari, P., 2019. Exploring the Free Energy Landscape To Predict the Surfactant Adsorption Isotherm at the Nanoparticle–Water Interface. *ACS Central Science*, 5 (11), pp.1804-1812. doi: 10.1021/acscentsci.9b00773
[2] Cardellini, A., Alberghini, M., Rajan, A.G., Misra, R.P., Blankschtein, D. and Asinari, P., 2019. Multi-scale approach for modeling stability, aggregation, and network formation of nanoparticles suspended in aqueous solutions. *Nanoscale*, *11*(9), pp.3979-3992. doi: 10.1039/C8NR08782B
[3] Bhowmik, A., Castelli, I.E., Garcia-Lastra, J.M., Jørgensen, P.B., Winther, O. and Vegge, T., 2019. A perspective on inverse design of battery interphases using multi-scale modelling, experiments and generative deep learning. *Energy Storage Materials*. doi: 10.1016/j.ensm.2019.06.011

External collaborations

- University of Manchester
- University of Trieste
- University of Illinois at Chicago (UIC)

Highlights of the research activity

Understanding and controlling new and advanced materials require the modeling of complex and dynamic processes. Many of these take place at the interfaces between material components of phases, which typically need a long simulation campaign to reproduce the phenomena and entail a massive amount of data to analyze. Not surprisingly, in recent years, it is increasingly evident that using simulation methods synergistically and machine learning tools hold the key to developing new high-throughput materials.
Therefore, during this first year, I started learning about the base of the MD and MC theory, and the mechanical statistic beyond these, to develop interface model at the nanoscale. Then, I approached a real system by studying the adsorption of surfactants on alumina nanoparticle (NP). This set-up represents a typical nanoscale interface phenomenon occurring in energy nanofluids. First, by coupling ModeFRONTIER with MD simulations, I have been able to evaluate the free energy profiles of adsorption. Second, I integrated the MD results with the Langmuir Theory of adsorption to predict the adsorption isotherm in the low concentration region, Figure 1. Our results are in good agreement with experimental data found in the literature. Furthermore, from this study, we observed an interesting phenomenon due to the curvature and heterogeneities in the NP surface morphology, which brings to a splitting of the free energy landscapes corresponding to various possible sites of adsorption. We finalized this work with a publication on ACS Central Science [1].
The future step is to learn about Machine Learning methods, i.e. Supervised (SVM, Neural Networks, etc.) and Unsupervised (kMeans, etc.) learning, and use these tools to study and understand Electrolyte Interface (SEI) in Ion-Lithium Battery.



(a) Mean steering work, ⟨W⟩, and the free energy change of adsorption, ΔG, as a function of the reaction coordinate ξ. 60, 40, 10, and 0 SDS molecules coating the target NP are modeled to compute the free energy landscapes (FELs) using Steered Molecular Dynamics (video). (b) Comparison of the developed model (green solid line) and experimental results (blue square marks) for predicting the surface density of adsorbed surfactants, Γ, given a specific bulk concentration in aqueous solution (C).

First name: Giovanna **LAST NAME**: DE LUCA

Topic: Advanced models for the building energy performance assessment

Course year: 1st **Tutors**: Vincenzo Corrado, Ilaria Ballarini

Academic context

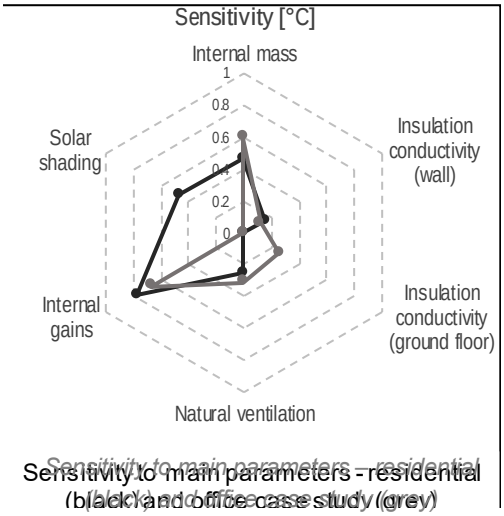
[1] van Dijk, D. EN ISO 52016-1: The new international standard to calculate building energy needs for heating and cooling, internal temperatures and heating and cooling loads. *In publishing* in Proceedings of Building Simulation 2019: 16th Conference of IBPSA (ISBN: 978-1-7750520-1-2). 1-4 September 2019, Rome.
[2] Crawley, D. B.; Hand, J. W.; Kummert, M.; Griffith, B. T. Contrasting the capabilities of building energy performance simulation programs. Building and Environment 2008, 43, 661-673.
[3] Johra, H.; Heiselberg, P. Influence of internal thermal mass on the indoor thermal dynamics and integration of phase change materials in furniture for building energy storage: A review. Renewable and Sustainable Energy Reviews 2017, 69, 19-32.

External collaborations

- EdilClima Engineering & Software

Highlights of the research activity

The issue of improving the energy performance in buildings has led to the rapid development of calculation methods for the building energy performance assessment, which must comply with the model requirements of accuracy, robustness, reproducibility, transparency and simplicity. The new EN ISO 52016-1 technical standard introduces a reference calculation method, aimed at providing a balanced accuracy and simplification. However, the new calculation model has to be tested in terms of its calculation assumptions and simplifications, and its opening up to alternative calculation methods should be explored as to increase its accuracy, while ensuring the compliance with the model requirements. Within this context, the Ph.D. research is focused on three main activities. An extensive and detailed literature review is currently carried out to increase the transparency and the awareness in the use of the dynamic simulation. The physical phenomena involved in the interaction between the building components are studied through a detailed component vs. component array, in which the calculation assumptions, boundary condition and equations are compared and catalogued. To identify the parameters that most affect the building energy performance is of crucial importance if the increase in the model's accuracy is investigated. Thus, a comprehensive uncertainty and sensitivity analysis has been performed in the field of the calibration of two existing case studies to the main building envelope and user behavior parameters. Preliminary results are shown in the attached figure; internal gains and internal mass showed a strong and relevant impact on the simulation output for both the considered case studies. The most influencing parameters highlighted through the sensitivity analysis will be analysed in depth in the field of the validation and the implementation of the recently introduced calculation model. In contrast to the sensitivity analysis which has been performed at a building (or thermal zone) level, the third activity will be focused on specific building components, such as the modelling of the internal heat capacity and the conduction through the building envelope. On the basis of a detailed literature review and of the results of the validation activity, numerical models able to solve the possible discrepancy and to provide the best trade-off between accuracy and simplifications will be developed.



Sensitivity to main parameters - residential (black) and office case study (grey)

First name: Giuseppe **LAST NAME**: DI PIERRO

Topic: Analysis, Development and Optimization of Automotive Electric Hybrid Powertrain Systems

Course year: 3rd **Tutor(s)**: Federico Millo

Academic context

[1] Cubito, C.; Rolando, L.; Millo, F.; Ciuffo, B.; Serra, S.; Trentadue, G.; Marcos Garcia, O.; Fontaras, G., "Energy Management Analysis under Different Operating Modes for a Euro-6 Plug-in Hybrid Passenger Car," SAE Tech. Pap. 2017.
[2] 1. DiPierro, G., Millo, F., Scassa, M., and Perazzo, A., "An Integrated Methodology for 0D Map-Based Powertrain Modelling Applied to a 48 V Mild-Hybrid Diesel Passenger Car," SAE Technical Paper 2018-01-1659, 2018, https://doi.org/10.4271/2018-01-1659.
[3] 2. DiPierro, G., Millo, F., Tansini, A., Fontaras, G. et al., "An Integrated Experimental and Numerical Methodology for Plug-In Hybrid Electric Vehicle 0D Modelling," SAE Technical Paper 2019-24-0072, 2019.

External collaborations

- FEV Italia s.r.l.
- FEV Europe GmbH
- Joint Research Ce

Highlights of the res

Benchmarking the most inn
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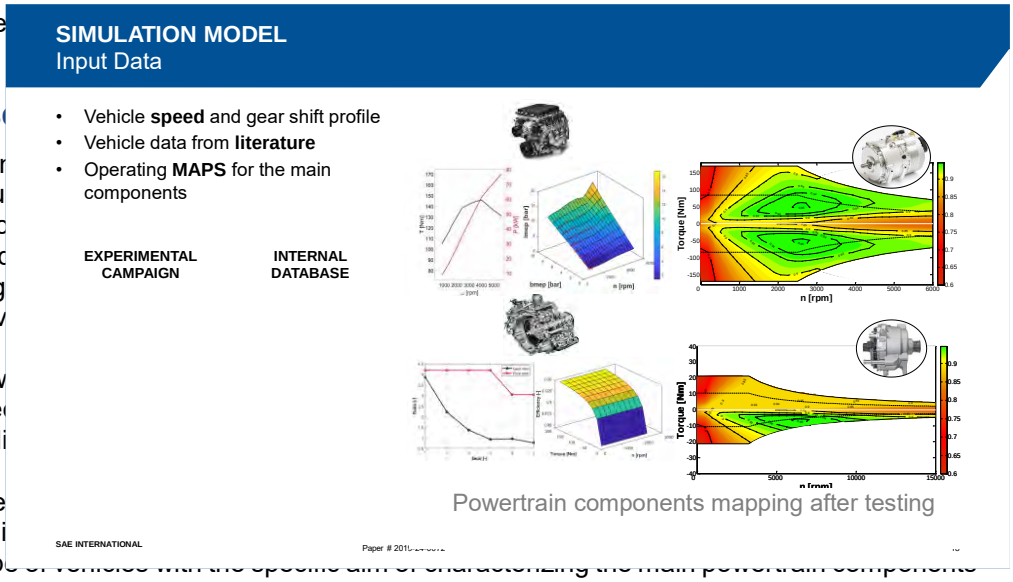
developed to test these typ
and understanding the powertrain control logics. The whole set of processed data were later used to develop a hybrid vehicle model it in a virtual environment. Additionally, I have been supporting the Joint Research Centre (JRC) of the European Commission in testing and analyzing HEVs and PHEVs for regulatory purposes, carrying out the simplified procedure.



Powertrain components mapping after testing

On the simulation side, I have co-developed a universal all-in-one hybrid electric vehicle model, in a 0D Matlab/Simulink environment: the simulation platform is capable of simulating the most important types of hybrid vehicles, independently of the powertrain architecture (series, P0, P1, P2, P3, P4) . The vehicle model is made up by blocks and triggers: it allows the user to enable only the desired characteristics, depending on the type of vehicle under investigation, without the need of building a dedicated model every time a new powertrain needs to be simulated. Each component is modelled on the physical side and on the controller side, by means of functional maps and state-machine blocks. Firstly, model calibration is based on big amount of data collected and post-processed during the above-mentioned experimental campaign. Powertrain control logics are also extracted from vehicle testing in order to predict the energy split between the ICE and the electric motor(s). It is also capable of predicting fuel consumption, CO2 and NOx emissions over real driving scenarios, Model capabilities are later validated and eventually it can be used as a tool in the predevelopment phase for the assessment of the potentialities of new hybrid powertrains.

First name: Nicolò **LAST NAME**: FALCONE

Topic: Power and passive decay heat removal in SMR power plant

Course year: 2nd **Tutor(s)**: Cristina Bertani, Mario De Salve

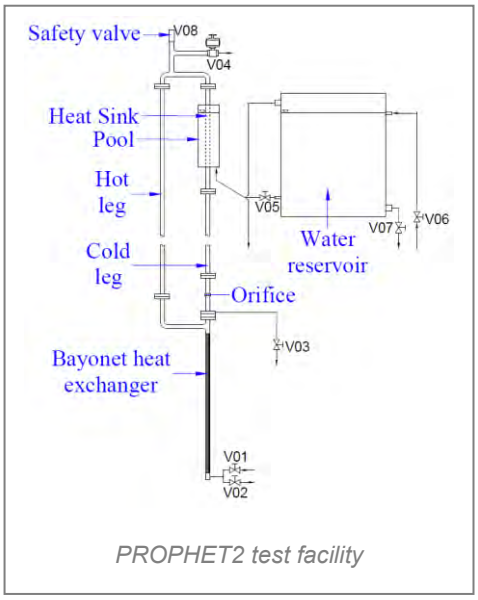
Academic context

[1] C. Bertani, N. Falcone, A. Bersano, A. Azzarone, M. De Salve, B. Panella, Experimental study of a natural circulation loop and RELAP5-3D analysis, Proceedings of 37th UIT Heat Transfer Conference, June 24-26, 2019, Padova (Italy).
[2] A. Bersano, N. Falcone, C. Bertani, M. De Salve, F. Mascari, C. Lombardo, Validation of RELAP5-3D thermal-hydraulic code against full-scale PERSEO Test 9, Proceedings of International Congress on Advances in Nuclear Power Plants – ICAPP 2019, May 12-15, 2019, Juan-les-pins (France).
[3] A. Bersano, N. Falcone, C. Bertani, M. De Salve, B. Panella, Conceptual design of a bayonet tube steam generator with heat transfer enhancement using a helical coiled downcomer, Progress in Nuclear Energy, 108, pp. 243-252, 2018.

External collaborations

- ENEA
- SIET

Highlights of the research activity



PROPHET2 test facility

During this year of PhD activity, the study of passive heat removal systems based on natural circulation has been continued. The analysis of the experimental data acquired with the PROPHET facility built at Politecnico di Torino led to the identification of different phenomenological windows that allows to separate the effect of the different phenomena during the transient evolution of the system. This work was presented at the 37th UIT Heat Transfer Conference held in Padova in June 2019. In order to increase the thermal power that can be provided to the system, the geometrical design of the bayonet heat exchanger has been slightly modified and new electrical heaters have been installed. The new configuration, named PROPHET2, has been used to perform a new experimental campaign aimed at the investigation of the effect of different water inventories and electric power provided on the system behavior. The analysis of the experimental data acquired is still undergoing and aims to the identification of the initial and boundary conditions that lead to the development of liquid single-phase natural circulation and two-phase natural circulation. The experimental data have been compared with the numerical results provided by the simulations performed with the system code RELAP5-3D. Different nodalization strategies have been tested in order to check the correctness of the nodalization. The comparison shows a quite good agreement in particular for the case of liquid single-phase natural circulation, while deeper investigation is required for the two-phase natural circulation with presence of non-condensable gases. In the framework of the application of the uncertainty quantification methods coupled with thermal hydraulic system code, the RELAP5-3D code has been coupled with the RAVEN code. Some initial and boundary condition together with some input parameter used for the RELAP5-3D simulations of the PROPHET2 facility have been selected and used to perform a sensitivity analysis and compute basic statistical parameters. The first results obtained allow to get a qualitative indication on which are the input parameters that mostly affect the system response but further improvement are required in order to get a quantitative evaluation of the effect of different parameters on the system behavior.

First name: Gabriele **LAST NAME**: FAMBRI

Topic: Energy storage and conversion technologies to improve renewable energy penetration

Course year: 1st **Tutor(s)**: Marco Badami

Academic context

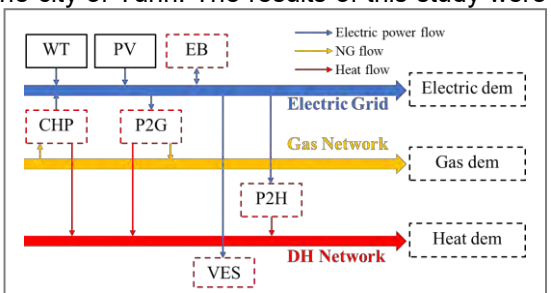
[1] Badami M, Fambri G. Optimising energy flows and synergies between energy networks. Energy, 2019,173,400-412.
[2] Kötter E, Schneider L, Sehnke F, Ohnmeiss K, Schröer R. The future electric power system: Impact of Power-to-Gas by interacting with other renewable energy components. Journal of Energy Storage, 2016, 5,113-119.
[3] Connolly D, Lund H, Mathiesen BV: Smart Energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union. Renewable and Sustainable Energy Reviews, 2016, 60, 1634-1653.

External collaborations

- CERTH - Centre for Research and Technology Hellas, Thessaloniki (Greece)
- LINKS Foundation - Leading Innovation & Knowledge for Society
- VTT - Technical Research Centre of Finland

Highlights of the research activity

My PhD research activity carried out during the first year was mainly performed within the EU H2020 project PLANET (Planning and operational tools for optimising energy flows & synergies between energy networks), which is developing a holistic Decision Support System that aims to facilitate the integration of renewable energy in the electricity grid by using energy conversion and storage technologies.
In summary, my research work can be divided into three different main activities:
i) the development of the first prototype of the Decision Support System (DSS) for the PLANET project. This tool was built in the MATLAB/Simulink environment and simulates the energy flows of electricity, heat and natural gas in district/city energy scenarios, and the operation of energy conversion and storage as connectors between the energy networks. The tool exploits the flexibility of the storage and conversion technologies in order to increase the renewable energy penetration. I have also collaborated with the research group of CERTH (Greece) to create a web interface that allows the user to use this program remotely. This work led to the preparation of the paper "A Decision Support System tool to manage the flexibility in renewable energy-based power systems", currently under revision by the journal “Energies”;
ii) analysis of the impact of P2H and P2G energy conversion technologies and electrochemical storage (EB) systems in a future high RES penetration energy scenario. In this part of the research the tool was used to simulate a realistic scenario based on real data pertaining to the city of Turin. The results of this study were summarized in the paper "Optimising energy flows and synergies between energy networks", published in the journal “Energy”;
iii) development of a thermodynamic model of a building. The model was used to simulate the flexibility of buildings’ heating / cooling demand by modifying the internal set point temperature in order to use buildings as Virtual Energy Storage (VES). The VES model was applied to simulate the energy consumption of a residential area of Turin. Then, the exploitation of this flexibility source was compared with the flexibility of the other energy conversion and storage technologies. This work is in progress and the main results will be discussed in a paper to be submitted to an international journal.



Energy conversion technologies as connectors between energy networks

First name: Vincenzo **LAST NAME**: GENTILE

Topic: Enhancing Solar Desiccant Systems

Course year: 3nd **Tutor(s)**: Marco Simonetti, Forrest Meggers

Academic context

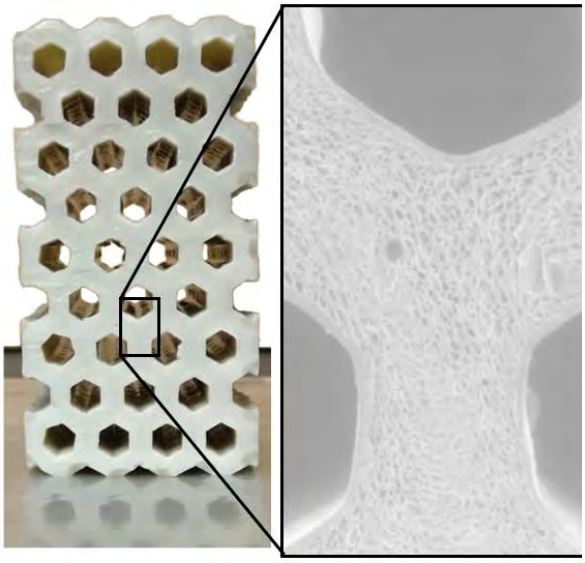
[1] V. Gentile, M. Simonetti, P. Finocchiaro, G.V. Fracastoro. (2017). Water production from the atmosphere in arid climates using low grade solar heat. ISES Solar World Congress 2017. doi:10.18086/swc.2017.17.02.
[2] P.Finocchiaro, M.Beccali, V.Gentile, 2016. Experimental results on adsorption beds for air dehumidification. International Journal of Refrigeration 103, 781-789.
[3] M.Simonetti, V.Gentile, G.V.Fracastoro, A.Freni, L.Calabrese, G.Chiesa, 2016. Experimental testing of the buoyant functioning of a coil with SAPO34 zeolite, designed for solar DEC (Desiccant Evaporative Cooling) systems of building with natural ventilation. Applied Thermal Engineering 103, 781-789.

External collaborations

- Princeton University, Andlinger Center for Energy + Environment (F.Meggers)
- CNR – ICOOM (A. Freni)
- Politecnico di Milano, Dipartimento Energia (M.Motta)

Highlights of the research activity

Activities carried out in this research fit with the set of sustainable development actions for the sectors of cooling and clean water (SDG 6 and 7). The technological challenge of water vapor/air separation and recovery is assessed investigating the use of hygroscopic materials (Silica gel and Zeolite), through the phenomenon of physic sorption. Applications in the cooling sector lead for a shift of the demand from power to heat such that, when combined with solar energy, the environmental sustainability of the sector is improved. The investigation of innovative adsorption heat exchangers designed for the humidity control in air conditioning has been carried out combing the numerical modelling of heat and mass transfer phenomena with experimental activities for performances evaluation. Same technological solutions are also applied to harvest water vapor from atmosphere and use it as an alternative source of fresh water for regions affected by water scarcity problems.



Hygroscopic porous structure realized with a bio-polymer derived from algae, for water vapor capture

Main research features on this topic are the definition of an efficient thermodynamic cycle, operated through the day/night alternation, thermally activated in the temperature range of 50-80 °C, involving biocompatible materials with enhanced hygroscopic properties for arid climates. Experimental tests of a prototype, performing the proposed cycle at different climatic conditions (T_{amb} 20-40°C), have demonstrated a production from 3 to 10 liters/day of distilled water, depending on the operative conditions. The development of an innovative composite bio-polymer, based on the sodium alginate and bentonite, improved the vapor capture capacity. The Sodium Alginate, a natural polysaccharide, is combined with Bentonite, an hygroscopic aluminum phyllosilicate clay, realizing porous and complex structures through ionotropic gelation manufacturing methods.

First name: Prashant **LAST NAME**: GOEL

Topic: Development of advanced CFD models for CNG combustion simulation in SI engines and gas turbines

Course year: 2nd **Tutor(s)**: Mirko Baratta, Daniela Misul

Academic context

[1] Baratta, M., Misul, D., Goel, P., Laurenzano, D. et al., "Experimental and Numerical Analysis of Diluted Combustion in a Direct Injection CNG Engine Featuring Post- Euro-VI Fuel Consumption Targets," SAE Technical Paper 2018-01-1142, 2018, https://doi.org/10.4271/2018-01-1142.

[2] Baratta, M., Misul, D., Xu, J., Fuerhapter, A. et al., "Development of a High Performance Natural Gas Engine with Direct Gas Injection and Variable Valve Actuation," SAE Int. J. Engines 10(5):2535-2551, 2017, https://doi.org/10.4271/2017-24-0152.

[3] Veynante,D., Vervish, L., "Turbulent combustion modelling" doi: doi.org/10.1016/S0360-1285(01)00017-X.

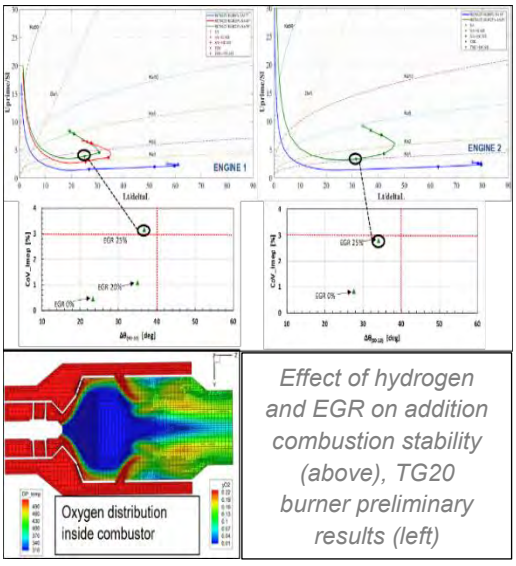
External collaborations

- Renault Technocenter, France
- IFP Energies Nouvelles, France
- ETHOS Energies, Italy

Highlights of the research activity

My research work started with the study of EGR limit for a dedicated mono-fuel direct injection Natural gas (NG) engine. This project has been the part of EC collaborative project (H2020 program). Aiming at achieving the goal of technological development in NG engine, Politecnico di Torino along with Renault and IFPEN, developed and calibrated a 3D CFD model to understand the intrinsic phenomenon of gas motion, mixture formation, combustion and exhaust gas temperatures. This activity includes many novel ideas to improve the efficiency of the CFD model some of which includes laminar flame speed sub-model to improve the combustion speed prediction with EGR. Moreover, this study has been extended to include the centrally mounted direct injection and the effect of injection strategy on mixture formation, mixture breakdown at high and low loads. As this activity has been concluded, the research deliverables have been submitted and 2nd research paper is under progress.

Second activity I have been involved in this year has been to understand the effect of EGR and hydrogen addition on low/high turbulent engines. As the turbulent kinetic energy of an engine changes (in this case, due to change in induction ports), the EGR tolerance changes as more EGR can be consumed with high turbulence engines. The high burning velocity of hydrogen can be exploited to control the combustion instabilities (due to high EGR). This has been the goal of this activity to understand the combustion instabilities with the help of Borghi diagrams. Research paper on this activity is ongoing.



Effect of hydrogen and EGR on addition combustion stability (above), TG20 burner preliminary results (left)

Along with the activity mentioned above, a research project has been started with Ethos energies, with the objective to characterize the combustion of a gas turbine burner TG20 and compare the emissions (in terms of NOx and CO) with experimental data. The activity started with geometric development. Combustion and turbulence models have been evaluated along with the mesh sensitivity to accurately capture the mixing and combustion/turbulence interaction in primary and secondary phase of combustion. This activity will be extended to understand the effect of water addition in combustor and its effect on NOx. This activity is ongoing and will be finalized in 2020.

First name: Emerance J. Claire D'Assise **LAST NAME**: GOMA-TCHIMBAKALA

Topic: Bacteria and biosurfactants in the remediation of hydrocarbon-contaminated environments

Course year: 1st

Tutor(s): Stefano P. Corgnati, Stefano Lo Russo

Academic context

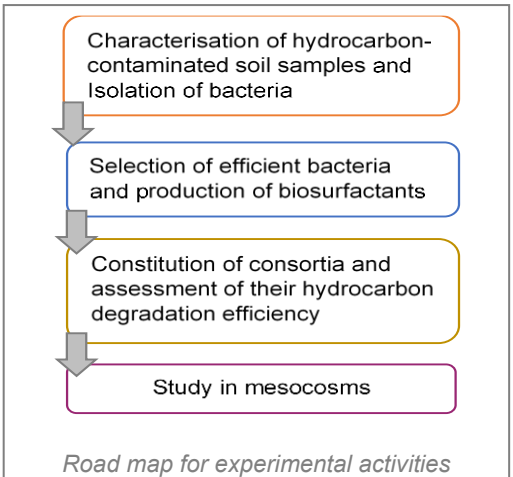
[1] Xu X, Liu W, Tian S, Wang W, Qi Q, Jiang P, Gao X, Li F, Li H, Yu H (2018) Petroleum Hydrocarbon-Degrading Bacteria for the Remediation of Oil Pollution Under Aerobic Conditions: A Perspective Analysis. Front. Microbiol. 9:2885.
[2] Borah Debajit and Yadav R N S. Bioremediation of petroleum-based contaminants with biosurfactant produced by a newly isolated petroleum oil degrading bacterial strain (2016). Egyptian Journal of Petroleum, 26: 181-188.
[3] Poddar Kasturi, Sarkar Debapriya, Sarkar Angana (2019) Construction of potential bacterial consortia for efficient hydrocarbon degradation. International Biodeterioration & Biodegradation 144 (2019) 104770.

External collaborations

- Eni spA.

Highlights of the research activity

The overall objective of the research is to build a bank of bacteria with bioremediation potential in order to develop highly efficient consortia of bacteria and the biosurfactants they synthesize, usable in the decontamination of hydrocarbon-polluted environments.
The methodology proposed to achieve this goal has been designed as an experimental process involving the isolation of bacterial biomass from hydrocarbon-contaminated soil samples as well as the production of the isolates metabolites (biosurfactants). This would afterwards culminate in the constitution of consortia and their subsequent inoculation in hydrocarbon contaminated matrices to assess their efficiency in hydrocarbon degradation.
During this year, access to laboratory in order to perform experiments has not been granted. Thus, the activities carried out focused on literature exploration and participation to scientific events (Hands-on training in Prokaryotic and Eukaryotic metagenomics ICME 10; 4th Energy for Sustainability International Conference, 4th International Mass spectrometry School; Biosurfactants 2019 conference) to inform the research and define a road map for its achievement.
In this context, the information collected from the research activities highlighted:



Road map for experimental activities

- the position of hydrocarbon pollution as a major contemporary global environmental challenge and consequently, the need to remediate sites contaminated with hydrocarbons;
- the use of bioremediation involving bacteria as a sustainable approach to tackle hydrocarbon contamination;
- the interest of employing bacterial consortia and biosurfactants to enhance hydrocarbon degradation;
- the need to use molecular biology tools as well as sensitive methods such as mass spectrometry and coupled techniques for an accurate identification of bacterial strains and their metabolites and a deep investigation of the quantitative and qualitative aspects of the hydrocarbon biodegradation process.

First name: Francesco **LAST NAME**: ISAIA

Topic: Exploiting the potential of adaptive building components by means of innovative control strategies

Course year: 3rd **Tutor(s)**: Alfonso Capozzoli, Valentina Serra

Academic context

[1] Aste N., Manfren M., Marenzi G., Building automation and control systems and performance optimization: a framework for analysis, Renewable and Sustainable Energy Reviews; Volume 75, 2017, pp.313–330; ISSN 1364-0321; http://dx.doi.org/10.1016/j.rser.2016.10.072
[2] Favoino F., Goia F., Perino M., Serra V., Experimental analysis of the energy performance of an ACTive, RESponsive and Solar (ACTRESS) façade module, Solar Energy, Volume 133, 2016, pp.226-248, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2016.03.044
[3] Fiorentini M., Wall J., Ma Z., Braslavsky J.H., Cooper P., Hybrid model predictive control of a residential HVAC system with on-site thermal energy generation and storage, Applied Energy; Volume 187; 2017; pp. 465-479; ISSN 0306-2619; https://doi.org/10.1016/j.apenergy.2016.11.041

External collaborations

- ENEA
- Sustainable Buildings Research Centre (SBRC) of the University of Wollongong (UOW)

Highlights of the research activity

Electrochromic façade in a TWINS cell

Building façade systems have seen significant improvements over the last years, with the result of enabling modern buildings to adapt and respond to dynamic boundary conditions, in order to meet the users' comfort needs while reducing the building energy demand; however, advanced control strategies need to be explored with the aim of exploiting adaptive capabilities during building operation. In this context, a thorough research activity was carried out to build a comprehensive picture on the current progress of responsive technologies for building façades and control strategies, with a special focus on Model Predictive Control.

Common research interests with the Sustainable Buildings Research Centre of the University of Wollongong led to an ongoing collaboration with the aim of exploring the opportunities offered by active façades equipped with an electrochromic glazing, which can be electrically controlled to change its light and solar transmission properties. The contrasting needs concerning visual and thermal comfort are of crucial importance. On the one hand, increasing the glazing transparency leads to an increase of daylight in the indoor environment, thus reducing the energy needs for artificial lighting; on the other hand, an increase in exogenous heat gains via solar radiation occurs, leading to potential increases in cooling energy needs. It is indeed essential to search a trade-off between these contrasting goals: Model Predictive Control (MPC) algorithm merges feedback control principles and numerical optimization, making it a promising solution to manage electrochromic adaptive façade systems.

A currently ongoing research activity deals with next-generation electrochromic glazing, which were used to build a real-scale façade in one cell of the TWINS facility, placed at the DENERG rooftop. Experimental campaigns were performed in order to build and calibrate a white-box model, which enabled (through its surrogated dataset) the construction and identification of a grey-box model. With a reliable reduced model, it was then possible to design different MPC strategies, which were later implemented using co-simulations tools. The outcomes of these activities highlight the importance of control strategies on active building components, and show how an advanced control such as the MPC on the one hand opens a new set of possibilities and on the other hand enhances the performance of these systems.

First name: Zhiru **LAST NAME**: JIN

Topic: Fluid dynamics of internal combustion engines – diesel injection systems

Course year: 1st **Tutor(s)**: Alessandro Ferrari

Academic context

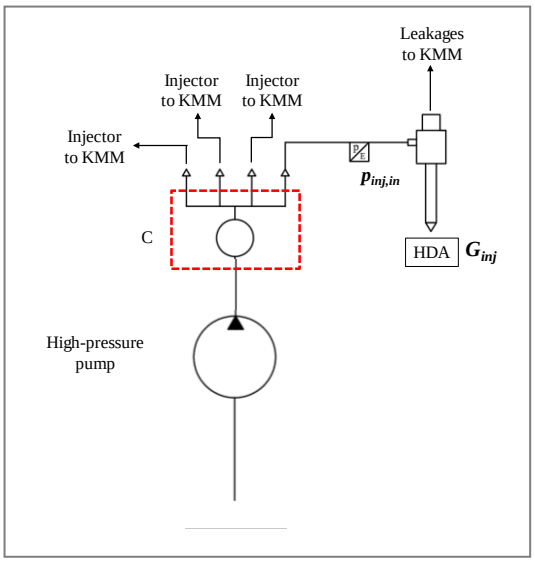
[1] Ferrari A, Mittica A, Pizzo P, Jin Z. 2018. PID controller modelling and optimization in Cr systems with standard and reduced accumulators. International Journal of Automotive Technology, Accepted.
[2] Ferrari A, Jin Z, Mittica A, Vento O, Zhang T, Ouyang L, Tan S. 2019. Application of the common-feeding injection system layout to light duty commercial vehicle diesel engines. Proceedings of the ASME 2019 Internal Combustion Engine Division Fall Technical Conference, Accepted.

External collaborations

- Nanyue Fuel Injection Systems Co., Ltd

Highlights of the research activity

The first activity is related to the CR systems. The proportional-integrative-derivative (PID) controller and the pressure control valve of a Common Rail system have been modelled and optimized in a previously developed model of the CR fuel injection system from electronic, electrical, hydraulic and mechanical aspects. Under steady-state and transient working conditions, based on the model results, PID controller coefficients have been studied and illustrated. Moreover, the rail pressure time history has been investigated by varying the accumulator size under the condition when the rail volume has been dramatically reduced (up to 2.5 cm^3). This is realized by the new predictive model and is applied to optimize the high-pressure control system where the rail is removed with the help of possible suitable PID controller parameters.
Another project still concerns the CR system with an innovative apparatus which is without the rail. A Chinese firm (Nanyue Fuel Injection Systems Co.,Ltd) has financed this activity for the aim of reaching a prototype of this new fuel injection system (CF system). The innovative Common Feeding (CF) fuel injection system has been designed for the aim of reducing production costs and allowing easy installation on the engine, compared to a traditional Common Rail system. The idea is based on a patent recently made at Politecnico. The experimental tests have been carried out on both the CR and the CF systems in terms of single and pilot-main injections. Based on the collected experimental data for the different rails, it is found that the varied rail size or shape has little effect on the injection performance of the fuel injection system. In this way the diesel injection system prototypes aiming to fulfill China future emission targets have been realized.The last activity is about a new injected quantity estimation Method for passenger car common rail injection systems. It has been realized through the time-frequency analysis applied to the pressure signal captured by one sensor along the rail-to-injector pipe. By detecting the SOI and EOI of the injection event, injection temporal length (ITL) has been obtained. The correlations between the injection temporal lengths (ITL) and injected masses (Minj) at different pnom values have been made and they hold independently of the fuel temperature.
The estimated injected mass can be evaluated by inserting the pnom and the ITL values into the obtained correlation. The experimental campaign has been repeated over a wide range of single injection working conditions. The accuracy of the innovative injected mass prediction methodology has been verified: the overall error is always within 1.5 mg.



The schematic layout of the high-pressure circuit of the CF system.

First name: Claudio **LAST NAME**: MAINO

Topic: (P)HEV Optimal Design

Course year: 1st **Tutor(s)**: Daniela Misul, Ezio Spessa

Academic context

[1] Bertsekas, D. P., Bertsekas, D. P., Bertsekas, D. P., & Bertsekas, D. P. (2005). Dynamic programming and optimal control (Vol. 1, No. 3). Belmont, MA: Athena scientific.
[2] Finesso, R., Spessa, E., & Venditti, M. (2014). Layout design and energetic analysis of a complex diesel parallel hybrid electric vehicle. Applied Energy, 134, 573-588.
[3] Anselma, P. G., Belingardi, G., Falai, A., Maino, C., Miretti, F., Misul, D., & Spessa, E. (2019, July). Comparing Parallel Hybrid Electric Vehicle Powertrains for Real-world Driving. In 2019 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE) (pp. 1-6). IEEE.

External collaborations

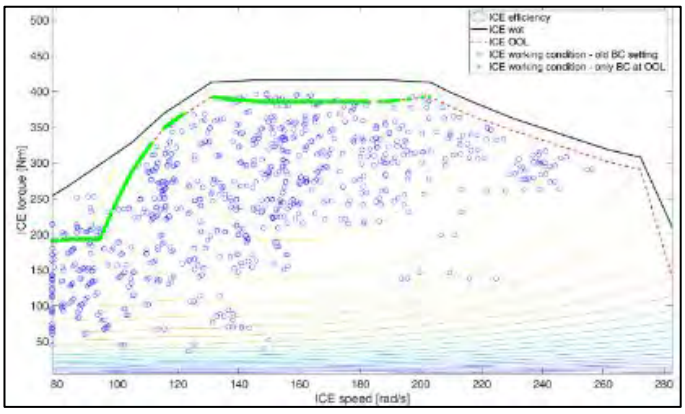
- FPT Industrial
- AVL Italia S.r.l.

Highlights of the research activity

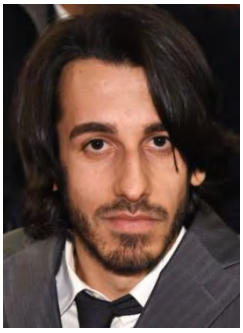
- **Development of an innovative tool for performing design operations over hybrid vehicles fleets (research project in collaboration with FPT Industrial).**
  A relevant amount of (P)HEV solutions might be exploited so to optimize a specific target function (e.g. fuel consumption) over different driving scenarios (regulation cycles or real driving missions). The design tool developed within this framework allows the user to explore a customizable design space (in terms of powertrain design variables) while evaluating the performances of any tested (P)HEV layout. Therefore, given the necessity of providing the user with a realistic ranking of layouts based on the specific optimization target, the test cases are evaluated by means of an optimized Dynamic Programming algorithm (an example in Fig. 1). The optimization target of each simulation is equal to the optimization target of the overall design procedure.

- **Development of Machine Learning and Deep Learning approaches for automotive applications.**
  A benchmark (P)HEV control strategy shows the potential of exploiting the best performance achievable by a given architecture over a specific driving mission. Although global optimizers (such as Dynamic Programming) can perfectly fit offline optimizations, they cannot be accounted as real-time controllers due to their necessity of having a priori knowledge about the driving scenario. For the purpose of exploring new solutions with respect to the actual ones (e.g. rule-based controllers or ECMS), Machine Learning or Deep Learning algorithms have been deeply analyzed and applied to two automotive applications:

  - Virtual sensors for pollutants estimation
  - (P)HEV real-time control as Deep Learning supervised problem



Example of ICE operating points during battery charging (BC) phases when the Dynamic Programming is forced to maintain ICE working operation on the fuel consumption optimal operating line (OOL)



First name: Alessandro **LAST NAME**: MANCARELLA

Topic: PCCI concept and combustion control techniques on a 3.0 l diesel engine

Course year: 3rd **Tutor(s)**: Stefano d'Ambrosio

Academic context

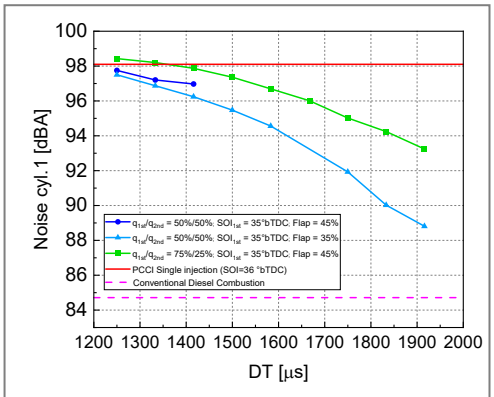
[1] d'Ambrosio S., Iemmolo D., Mancarella A., Vitolo R., "Preliminary optimization of the PCCI combustion mode in a diesel engine through a design of experiments", 71st Conference of the Italian Thermal Machines Engineering Association, ATI2016, 14-16 September 2016, Turin, Italy.
[2] Spessa, E., d'Ambrosio, S., Iemmolo, D., Mancarella, A. et al., "Steady-State and Transient Operations of a Euro VI 3.0L HD Diesel Engine with Innovative Model-Based and Pressure-Based Combustion Control Techniques," SAE Int. J. Engines 10(3):1080-1092, 2017, doi:10.4271/2017-01-0695.
[3] d'Ambrosio, S., Gaia, F., Iemmolo, D., Mancarella, A. et al., "Performance and Emission Comparison between a Conventional Euro VI Diesel Engine and an Optimized PCCI Version and Effect of EGR Cooler Fouling on PCCI Combustion," SAE Technical Paper 2018-01-0221, 2018, doi:10.4271/2018-01-0221.

External collaborations

- FPT Motorenforschung AG, Arbon (SWI)

Highlights of the research activity

At first, the potentialities of premixed charge compression ignition (PCCI) concept have been evaluated on a production diesel engine. PCCI is a non-conventional diesel combustion mode able to reduce simultaneously both nitrogen oxides (NOx) and soot emissions, and it has been preliminarily achieved by advancing the timing of a single-pulse injection, to give enough time to the fuel to mix with the intake oxygen, and applying high EGR rates, to decrease in-cylinder flame temperatures. Several drawbacks related to PCCI were found, including higher unburned hydrocarbons (HC) and CO emissions, increased combustion noise (CN), lower fuel economy and deteriorated combustion stability. Proper hardware modifications (e.g., reduced compression ratio, modified piston shape, reduced injector cone angles, bigger EGR cooler and smaller turbo-group) were implemented on the production version of the engine, giving the possibility to reach a suitable steady-state PCCI calibration on a wider area of the engine map. Then, possible strategies were investigated to limit the typical drawbacks preventing the PCCI concept to be implemented in real vehicle applications.
The robustness of real-time combustion controllers have been tested, in both conventional diesel combustion and PCCI operations, with the aim of controlling the combustion barycenter in terms of MFB50 (crank angle at which 50% of the injected fuel has burnt), by properly shifting, on a cycle-to-cycle base, the start of injection (SOI) of the main pulse. Benefits in terms of enhanced combustion stability were highlighted, proving that real-time combustion controllers could effectively reduce the typical PCCI instability due high EGR and its possible uneven distribution among cylinders.
Hot (uncooled) EGR strategies (i.e. exhaust gas recirculated without passing through the EGR cooler) were tested in the lowest area of the engine map, with the aim of addressing the increase in tailpipe HC and CO emissions when the exhaust gas temperatures are so low that the DOC does not exploit its full effectiveness.
Finally, multi-pulse fuel injection strategies have been compared to the baseline single-pulse PCCI concept. Splitting the fuel injection pattern turned out to help the reduction of engine-out HC and CO emissions, optimizing the spray penetration and reducing the occurrence of over-mixing and wall impingement phenomena, with minor penalties in terms of soot and NO_x. Multi-pulse injection strategies also allowed to effectively dampen excessive CN levels, while making fuel consumption slightly increasing with the number of fuel injection pulses.



CN reduction of early multi-pulse injection PCCI operations

First name: Andrea **LAST NAME**: MANELLI

Topic: Engine technologies for reduction of fuel consumption and pollutant emissions in light-duty diesel engines with model-based and sensor-based controllers

Course year: 1st **Tutor(s)**: Stefano d'Ambrosio, Roberto Finesso

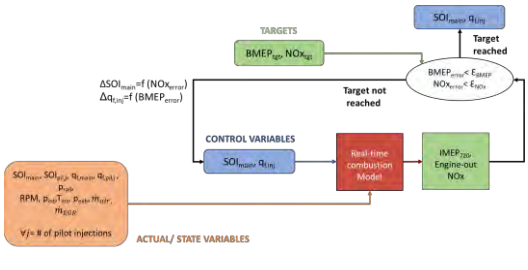
Academic context

[1] Hu, S.; d'Ambrosio, S.; Finesso, R.; Manelli, A.; Marzano, M.R.; Mittica, A.; Ventura, L.; Wang, H.; Wang, Y. "Comparison of Physics-Based, Semi-Empirical and Neural Network-Based Models for Model-Based Combustion Control in a 3.0 L Diesel Engine". Energies 2019, 12, 3423. doi: https://doi.org/10.3390/en12183423
[2] Manelli, A.; Finesso, R.; d'Ambrosio, S.; and Ventura, L.; "Model-Based Control of Torque and Nitrogen Oxide Emissions in a Euro VI 3.0L Diesel Engine through Model-in-the-Loop", 74° Congresso Nazionale ATI, Modena, 2019. In press.

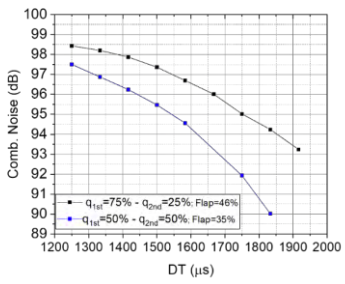
External collaborations

- FPT Industrial (FPT Motorenforschung AG research center in Arbon)

Highlights of the research activity



Scheme of the BMEP/ NOx controller



CN reduction for the PCCI double injection strategy

My first year of PhD research focused on the development of a model-based controller of torque (BMEP) and NOx engine-out emissions on the basis of the injected fuel mass quantity (q_{main}) and the start of injection of the main pulse (SOI_{main}) in a Euro VI 3.0L F1C diesel engine, starting from a model-based technique that was previously developed for a 11.0L Euro VI diesel engine. This has included the assessment of the functionalities of the controller through Model-in-the-Loop tests (first implemented in the Matlab/ Simulink environment and then assessed by coupling it with a fast-running GT-power engine model) and the evaluation of the behavior of the above-mentioned controller on the real engine (F1C 3.0L diesel engine) through Rapid Prototyping: to this aim, an oxygen sensor has been installed in the intake manifold in order to verify the possible benefits for the evaluation of NOx emissions by the model.
Another activity has focused on the evaluation of means to improve EGR effectiveness and the split injection strategy. An experimental campaign on a PCCI 3.0L engine has been performed to evaluate the effect of cold EGR, hot EGR and the number of injections on HC, CO emissions, BSFC and combustion noise (CN).

First name: Mohsen **LAST NAME**: MANSOURKIAEI

Topic: Optimization of control strategies of degradation management for power to power systems

Course year: 2nd **Tutors**: Massimo Santarelli, Domenico Ferrero

Academic context

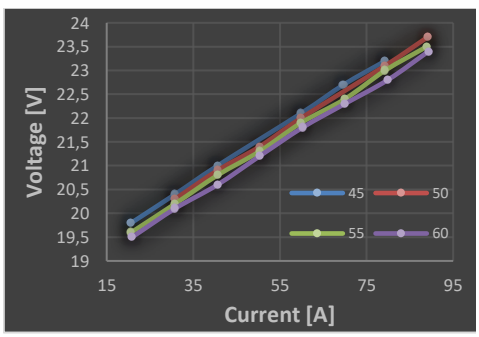
[1] A. Maheshwari, M. A. Dumitrescu, M. Destro, and M. Santarelli, "A modelling approach to understand charge discharge differences in thermal behaviour in lithium iron phosphate – graphite battery," Electrochim. Acta, vol. 243, pp. 129–141, Jul. 2017.
[2] F. J. Vivas, A. De las Heras, F. Segura, and J. M. Andújar, "A review of energy management strategies for renewable hybrid energy systems with hydrogen backup," Renew. Sustain. Energy Rev., vol. 82, pp. 126–155, Feb. 2018.
[3] T. Jahnke et al., "Performance and degradation of Proton Exchange Membrane Fuel Cells: State of the art in modeling from atomistic to system scale," J. Power Sources, vol. 304, pp. 207–233, Feb. 2016.

External collaborations

- ENGIE-EPS (Electro Power Systems Manufacturing S.r.l.) Industrial Plant in Turin, Italy
- SINTEF (Stiftelsen for industriell og teknisk forskning), headquartered in Trondheim, Norway
- CERTH (Ethniko Kentro Erevnas Kai Technologikis Anaptyxis), established in Thermi Thessaloniki, Greece

Highlights of the research activity

Considering the necessity to increase the penetration of renewable energy sources and integrate them with final loads through energy storage devices, the research aims to have a thorough control on the performance of novel technologies of power storage by studying the degradation of each of these system's elements (i.e.: batteries, FC/Electrlolyzer and hydrogen-based energy storage system) and the degradation of the overall system and interrelated effects of the elements. As a first step a series of experiments have been carried out in the facilities of the STEPS lab at Politecnico di Torino on the prototype of a high-pressure Polymer Electrolyte Membrane water electrolyzer. In this prototype anodic chambers are kept at almost atmospheric pressure, whereas the cathodic chambers are pressurized up to 7 MPa. Thanks to the developed electrochemical model and experimental data fitting it is possible to obtain the estimated values of some important process parameters and their trend in different temperature and pressure conditions. The result of the model and the experiments are series of polarization curves. Gathered experimental data were put in comparison with experiments carried out in similar condition with various time differences of over one year to find out whether the usage of the stack had an effect on the performance of the cells i.e.: degradation of the PEM stack in time. The results showed slightly higher cell voltage based on the polarization curves at different cathode pressures which lead to low degradation percentage of the PEM stack. Further development of the current model using more advanced theoretical approaches has been studied using new hypothesis. Following the experiments at the STEPS lab, experiments are being organized on the new test rig that is being installed at Environmental Park in Turin and financed by Piemonte Region as part of the INFRA-P CO_2 Circle Lab. This test bench aims at the characterization and performance evaluation of electrochemical devices for the production and utilization of hydrogen, but also including the auxiliaries appliances like the support Li-ion batteries. Current activities consist in assembly and validation of the test rig and selecting proper cells for the experimentation as well as further definition of the necessary variables to be inserted inside the control software.



Part of the Polarization curves of PEM stack at various constant temperatures (45,50,55,60°C) to study the degradation

First name: Marco **LAST NAME**: MARCHESE

Topic: Conversion of industrial CO_2 to value-added fuels and chemicals via Fischer-Tropsch upgrade

Course year: 2nd **Tutor(s)**: Andrea Lanzini, Massimo Santarelli

Academic context

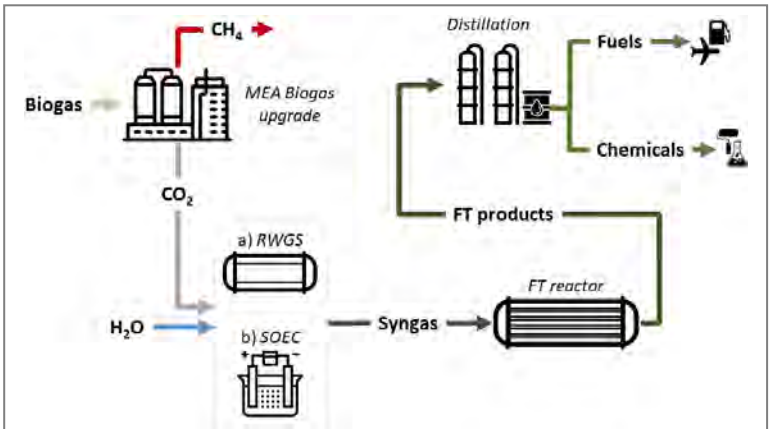
[1] M. Marchese et al., "Kinetic Study Based on the Carbide Mechanism of a Co-Pt/γ-Al_2O_3 Fischer–Tropsch Catalyst Tested in a Laboratory-Scale Tubular Reactor", Catalysts, vol 9, pp. 717-736, 2019.
[2] R. Yang et al., "Effects of experimental operations on the Fischer-Tropsch product distribution", Catal.Today, vol. 298, pp. 77–88, 2017.
[3] S. Jarvis et al., "Technologies and infrastructures underpinning future CO_2 value chains: a comprehensive review and comparative analysis", Renew. Sustain. Energy Rev., vol 85, pp. 46-68, 2018.

External collaborations

- VTT Technical Research Centre of Finland
- Ineratec GmbH
- Northwestern University

Highlights of the research activity

The PhD research activities are carried out within the framework of the EU H2020 project ICO2CHEM. The project aims at demonstrating the technical and economic feasibility of the installation of a Mobile Synthesis Unit, recycling industrial CO_2 to value-added Fischer-Tropsch products (i.e. synthetic oils and chemicals), with a Reverse Water Gas Shift (RWGS) in series with a microchannel Fischer-Tropsch reactor. The first converts CO_2 to CO, the latter synthetizes hydrocarbons via the reaction $CO+H_2 \rightarrow -CH_2-+H_2O$. Within the PhD**,** a detailed kinetic model as carbide mechanism has been deveolped. The model has been validated with a non-linear regression procedure on experimental results obtained in partnership with the project partner VTT. A Co/Pt-Al_2O_3 catalyst for low temperature Fischer-Tropsch applications has been tested at several temperature, pressure and H_2/CO molar ratio conditions (200-230°C, 15-30 bar, 1.06-2.11, respectively). The kinetic model well describes the instrinsic behaviour of the catalyst, with a mean absolute relative residual of 41%. Different carbon capture and utilization routes for power-to-liquid applications have been studied from a process analysis stand point of view, spanning from the capture of CO_2 to the generation of synthetic products. CO_2 is recovered from a solvent-based biogas upgrading unit. Two different routes for syngas generation have been investigated starting from the captured CO_2: one is a proven and commercially available technology like the RWGS reactor; the other one is a solid oxide electrolyer (SOE). The resulting syngas is fed to a Fischer-Tropsch (FT) reactor whose behaviour is described by the previosuly described kinetic model. The aim of the process analysis work is to find the most economically viable solution that can maximize the synthesis of middle distillates and waxes fraction, maximize the conversion of carbon dioxide and minimize the thermal requirements of the system. Finally, the optimal energy integration of each configuration plant was found. The best model configurations reach a plant efficiency of 81.1% in the case of solid oxide electrolyser as syngas generator, and 71.8% in the case of reverse water gas shift option, with a global carbon reduction potential of 79.4% and 81.7%, respectively.



Schematics of the proposed process model configurations for CO_2 conversion to FT products

First name: Omar **LAST NAME**: MARELLO

Topic: Development and assessment of model-based algorithms for torque and emission control in diesel engines

Course year: 2nd **Tutor(s)**: Roberto Finesso, Ezio Spessa

Academic context

[1] Finesso, R.; Hardy, G.; Mancarella, A.; Marello, O.; Mittica, A.; Spessa, E., "Real-Time Simulation of Torque and Nitrogen Oxide Emissions in an 11.0 L Heavy-Duty Diesel Engine for Model-Based Combustion Control", Energies 2019,12,460

[2] Finesso, R., Hardy, G., Maino, C., Marello, O., Spessa, E. "A New Control-Oriented Semi-Empirical Approach to Predict Engine-Out NOx Emissions in a Euro VI 3.0 L Diesel Engine", Energies 2017 10,1978

[3] Finesso, R., Marello, O., Misul, D., Spessa, E. et al., "Development and Assessment of Pressure-Based and Model-Based Techniques for the MFB50 Control of a Euro VI 3.0L Diesel Engine,"*SAE Int. J. Engines* 10(4):1538-1555

External collaborations

- FPT Motorenforschung AG
- *GM- Global propulsion systems (GM-GPS)*

Highlights of the research activity

Model-based combustion control techniques for internal combustion engines are becoming more and more interesting in the last years, due to the increasing computational performance of modern ECUs and to the increased complexity of engines (especially diesel engines). The adoption of this kind of control can give benefits in reducing the experimental effort required for engine calibration (compared with map-based approach) and could be useful to exploit the potential of real-time optimization techniques. In this framework two main activities have been carried out.

Within the HERCULES project, which was carried out in collaboration with GM-GPS, a real-time model-based torque controller has been developed. The aim of the controller is to provide the main injection fuel quantity in order to achieve a desired torque target, also in presence of multi after injection patterns.

The approach is based on the use of feed-forward ANNs (artificial neural networks), which have been trained using large virtual datasets simulated by a previously developed and calibrated low-throughput mean-value physical combustion model. ANNs are in fact able to replicate the results of the physical model with a high degree of accuracy, but they require a shorter computational effort, so that they can be implemented in the engine ECU within cycle-based high frequency tasks.

IMPERIUM project IVECO Stralis truck demonstrator

Within the IMPERIUM H2020 EU project an innovative model-based combustion controller/optimizer has been developed, which is capable of adjusting the main injection parameters in real-time (injection pressure, injection timing, injected fuel quantity), in order to achieve desired targets of torque and NOx emissions.

The controller has been integrated in a wider control system and receive the targets from an energy manager supervisor (EMS), which is able to exploit information coming from a dynamic eHorizon system to perform an on-board optimization of the energy sources and fluxes in the vehicle.

At the end of the project the whole IMPERIUM system (including all the sub-functions developed by all the project partners) has been tested and validated on a vehicle demonstrator (IVECO Stralis, Fig. 1) in public roads, over a high-road long-haul mission.

First name: Paolo **LAST NAME**: MAROCCO

Topic: Analysis of different power-to-power (P2P) configurations for electrical energy storage

Course year: 2nd **Tutor(s)**: Massimo Santarelli, Andrea Lanzini

Academic context

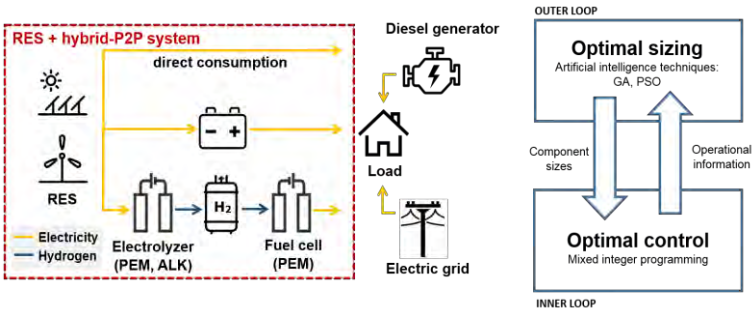
[1] F. J. Vivas et al. "A review of energy management strategies for renewable hybrid energy systems with hydrogen backup," Renew. Sustain. Energy Rev., vol. 82, no. Part 1, pp. 126–155, 2018.
[2] Q. Feng et al., "A review of proton exchange membrane water electrolysis on degradation mechanisms and mitigation strategies," J. Power Sources, vol. 366, pp. 33–55, 2017.
[3] P. Marocco et al., "REMOTE project: techno-economic analysis of H2-based energy storage systems in remote areas", EFCF 2019, 3rd European Grid Service Markets Symposium, Lucerne (Switzerland),2019.

External collaborations

- SINTEF, Trondheim, Norway
- ENGIE Electro Power Systems (EPS), Rivoli, Italy
- Enel Green Power, Rome, Italy

Highlights of the research activity

My research is carried out in the framework of the EU H2020 project REMOTE (https://www.remote-euproject.eu/), whose aim is to demonstrate the techno-economic feasibility of hybrid H2-based / electric battery energy storage solutions supplied by renewable electricity and operated in remote areas (i.e., isolated micro-grids and off grid areas such as islands). My contribution is the analysis and optimal design of such power-to-power (P2P) systems.
First a techno-economic analysis was performed for the four DEMOs involved in the REMOTE project: outcomes of the simulations revealed that local RES coupled with a hybrid H2/battery storage system can drastically reduce (or even eliminate) the need for diesel engines or expensive and invasive grid connections. A sizing optimization process was then conducted by employing the heuristic genetic algorithm (GA) technique. The aim was to evaluate the optimal sizes of the various components, so as to guarantee the total load coverage with the minimum LCOE. Hydrogen was found to be helpful to store energy over a longer period of time and to avoid the over-dimensioning of batteries, thus reducing the final cost of electricity.
The development of proper energy management strategies (EMS) is required to reduce operational costs and achieve high system efficiency. The research is thus now focusing on the derivation of optimal control strategies for P2P systems by means of mixed inter programming. Degradation phenomena of components need also to be taken into account for a more accurate description and better assessment of the EMS.
To investigate the degradation of PEM systems, I joined, as a visiting researcher, the SINTEF Sustainable Energy Technology Department (SINTEF Industry, Trondheim, Norway), where I performed experimental tests on PEM electrolyzers (both single cell and stack). The monitoring of the release of fluoride ions from the PEM membrane was considered to analyze its chemical stability through ion chromatography. The most stressful operating conditions in terms of temperature and current density were thus identified. Results of the performed degradation studies will be useful for the derivation of appropriate P2P system control strategies.



Operating sketch of the hybrid power-to-power system (on the left) and sizing problem scheme (on the right)

First name: Jesus Alberto **LAST NAME**: MEJIAS TUNI

Topic: Multiscale modelling of tunnel fires

Course year: 2nd **Tutor(s)**: Vittorio Verda, Elisa Guelpa

Academic context

[1] Colella F., Rein, G., Verda V., Borchiellini R. and Torero, J.L., (2011). Time-dependent Multiscale Simulations of Fire Emergencies in Longitudinally Ventilated Tunnels. Fire Safety Science 10: 359-372. 10.3801/IAFSS.FSS.10-359
[2] Colella, F., Rein, G., Verda, V., & Borchiellini, R. (2011). Multiscale modeling of transient flows from fire and ventilation in long tunnels. Computers & Fluids, 51(1), 16–29.
[3] Cosentino, S., Mejias, J. et al. Integrating 1D and 3D modeling for the analysis of ventilation control in tunnels. ICHMT International Symposium on Advances in Computationsl Heat Transfer. January 2017.

External collaborations

- NIST (National Institute of Standards and Technology)

Highlights of the research activity

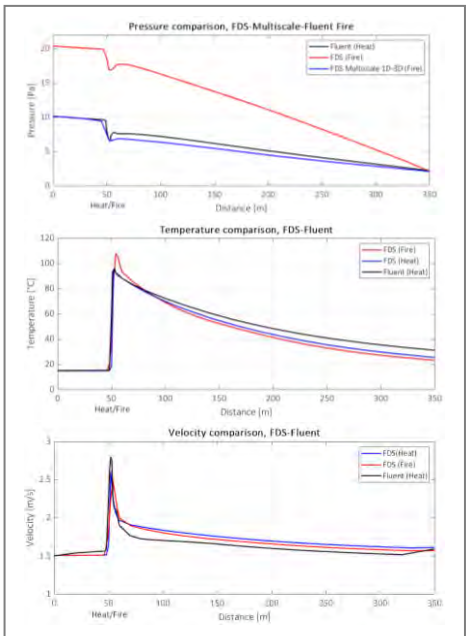
The Multiscale model has been tested several times to improve its precision. Simulations of full-scale tunnels were ran in Ansys Fluent and FDS to serve as reference points to evaluate the multiscale model accuracy. The accuracy of the Multiscale in the areas of temperature and velocity, as shown in Fig.1. Behave accordingly to the expected results. Still, the model uses FDS for the 3D calculation and the pressures obtained by it across the tunnel were different to the expected results. Observing this results and option found to achieve better pressure results was to create a pressure solver in the Multiscale model capable of using both the velocity and temperature outputs obtained by the FDS to translate them into a more consistent pressure curve.

The proposed procedure divides the tunnel into sections and calculates the pressure by applying the Bernoulli equation. The losses in each section are approximated using the Laplacian of the speed and the viscosity of the fluid. Using this procedure in each section gives the pressure difference in each part of the tunnel, summing all this pressure differences across the tunnel yields the pressure plot shown in fig.1.

The accuracy of the pressure obtained with this by-pass method not only improves the results obtained but also confirms that the pressure results obtained by the FDS are not correct, and that it is necessary to solve issues inside this code. Being the FDS a software recognized world-wide by the fire engineering community it is important to solve this kid of bugs inside the code.

Observing this problem some debugging and development was started with the people of NIST, as a Collaboration to solve this pressure issue and possibly introduce the Multiscale in the regular version of FDS.

Through this collaboration, that started in October of 2019, my research has moved temporally to the NIST in Gaithersburg, USA. Here the problems in tunnel simulations are being characterized to find a solution in the code and then introduce validation and verification cases that confirms the accuracy of FDS and Multiscale simulations in tunnels.



Pressure, Temperature and Velocity through the tunnel length for FDS (red), Fluent (black), and the Multiscale model (blue)

First name: Federico **LAST NAME**: MIRETTI

Topic: Integrated ICE-ATS management in (P)HEVs

Course year: 1st **Tutor(s)**: Daniela Misul

Academic context

[1] P.G. Anselma, G. Belingardi, A. Falai, C. Maino, F. Miretti, D. Misul, E. Spessa, "Comparing Parallel Hybrid Electric Vehicle Powertrains for Real-world Driving," 2019 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE), Torino, Italy, 2019, pp. 1-6. doi: 10.23919/EETA.2019.8804609
[2] Finesso, R., Spessa, E., & Venditti, M. (2016). Cost-optimized design of a dual-mode diesel parallel hybrid electric vehicle for several driving missions and market scenarios. Applied Energy, 177, 366-383.
[3] Finesso, R., Misul, D., Spessa, E., & Venditti, M. (2018). Optimal Design of Power-split HEVs Based on Total Cost of Ownership and CO2 Emission Minimization. Energies, 01 July 2018.

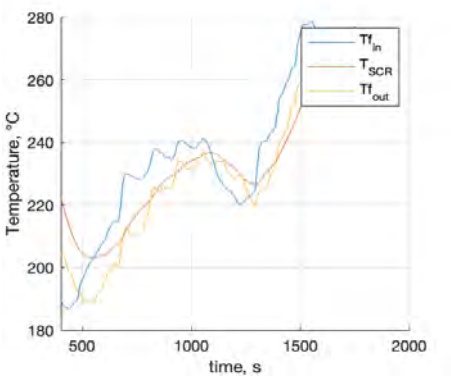
External collaborations

- FPT industrial
- IVECO
- ENI

Highlights of the research activity

The aim is to integrate the aftertreatment system (ATS) in a hybrid electric powertrain optimal design tool which was previously developed by the research group. The tool compares hybrid powertrain layouts fuel consumption and/or pollutants emissions over a given driving mission and the vehicle total cost of ownership over its lifespan. The fuel consumption and pollutants are evaluated based on an optimal energy management strategy obtained with Dynamic Programming.

As a first step of the activity, the first year's work has been focused on physical modelling of the ATS components. In particular, the biggest challenge is to model the SCR of a diesel-hybrid architecture, which is of particular concern to the industrial partner (FPT industrial) which will be a final user of the tool, while satisfying the conflicting constraints of good accuracy, low computational time and low calibration effort. The model must reach a good accuracy in describing the monolith's thermal dynamics in order not to bias the hybrid architectures ranking which is the main output of the tool; at the same time, it must a low computational cost, else the DP algorithm computational time would become too high for the tool to be relevant in an industrial application, and a low calibration effort to keep the tool flexible to new component specifications coming from within the industry.



The SCR temp and the gases outlet temp are evaluated as a function of inlet temp and mass flow rate

First name: Mohsen **Last name:** MOSAYEBNEZHAD

Topic: Thermo-fluid Dynamics in Gas Turbines

Course year: 2nd **Tutors:** Daniela Misul, Mirko Baratta

Academic context

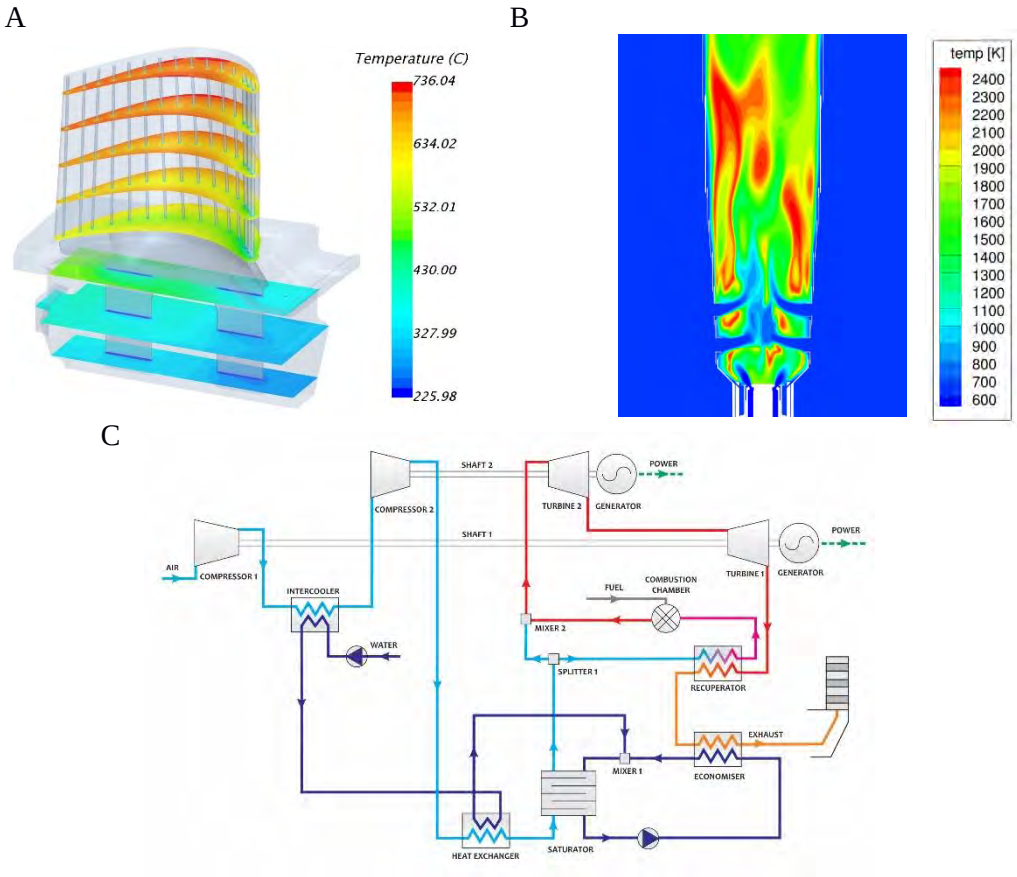
[1] Donini, A. (2014). Advanced turbulent combustion modeling for gas turbine application. Technische Universiteit Eindhoven. doi.org/10.6100/IR773140
[2] M. MosayebNezhad, A. S. Mehr , A. Lanzini, D. Misul, M. Santarelli, "Technology review and thermodynamic performance study of a biogas-fed micro humid air turbine", Journal of Renewable Energy, 2019. doi.org/10.1016/j.renene.2019.03.064

External collaborations

- EthosEnergy Italia
- Convergent Science
- Delft University of Technology

Highlights of the research activity

The first year of this PhD project was dedicated to develop multiscale and multidisciplinary models for the aim of conceptual design and technology modernization of gas turbine engines and ORC systems. Within this year different models were created and validated with experimental data for analyzing and optimization of combustion chamber, blade cooling, and design of the balance of plant using commercial and open source tools.



A) Conjugate heat transfer model created for an industrial axial gas turbine blade with internal cooling, B) Full scale 3D model of a gas turbine combustion chamber with both detailed and reduced chemistry mechanisms, and C) Proposed layout for a novel biogas fed micro humid air turbine installation in a wastewater treatment plant

First name: Giuseppe Francesco **LAST NAME**: NALLO

Topic: Modeling liquid metals for nuclear applications

Course year: 2nd **Tutor(s)**: Piero Ravetto, Roberto Zanino

Academic context

[1] G. F. Nallo, G. Mazzitelli, L. Savoldi, F. Subba, R. Zanino, "Self-consistent modelling of a liquid metal box-type divertor with application to the Divertor Tokamak Test (DTT) facility: Li vs. Sn", Nuclear Fusion 125, 206-59 (2019) 066020 (17 pp.), DOI: https://doi.org/10.1088/1741-4326/ab145b
[2] D. Caron, R. Bonifetto, S. Dulla, V. Mascolino, P. Ravetto, L. Savoldi, D. Valerio, R. Zanino, "Full-core coupled neutronic/thermal-hydraulic modelling of the EBR-II SHRT-45R transient", International Journal of Energy Research 42, 134-150 (2016), DOI: 10.1002/er.3571
[3] F. Lodi, G. Grasso, D. Mattioli, M. Sumini, "ANTEO+: A subchannel code for thermal-hydraulic analysis of liquid metal cooled systems", Nuclear Engineering and Design 301, 128-152 (2016), DOI: http://dx.doi.org/10.1016/j.nucengdes.2016.03.001

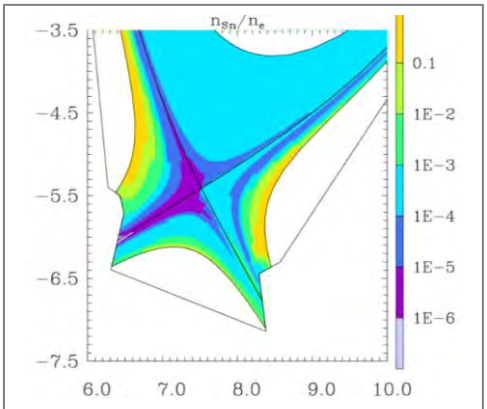
External collaborations

- ENEA (CR Bologna, CR Frascati)

Highlights of the research activity

This Ph.D. project involves the modeling of systems and components based on liquid metals (LMs) for both fusion and next generation fission nuclear reactors.

Fusion-related activities are focused on modeling innovative LM-based divertor concepts aiming at providing a reliable solution for the heat and particle exhaust problem in fusion reactors. Coating the divertor target with an LM-filled Capillary Porous Structure (CPS) has indeed the potential to significantly increase the component lifetime and resilience to transient events. During this year, the steady-state behavior of the SOL plasma in the presence of an LM divertor for the EU DEMO has been studied by means of the SOLPS-ITER code. This tool provides a multi-fluid description of the charged plasma species (e.g. H^+, Li^+, Li^{2+}, Li^{3+}) and a fluid or kinetic description of neutral species (e.g. H^0, Li^0), thereby allowing to evaluate the heat load profile on the target and the impurity flux entering the core plasma. The evaporation of Li or Sn from the target has been taken into account by self-consistently coupling SOLPS-ITER to a thermal model for the LM divertor. Figure 1 shows the computed distribution of the concentration of Sn ions. This work is part of the EUROfusion work package WPDTT1-LMD 2019, a European effort to develop a pre-conceptual design of an LM divertor.



SOLPS-ITER calculation of Sn concentration in the EU DEMO SOL in presence of an LM divertor

Fission-related activities involve modeling of Generation IV Lead-cooled Fast Reactors (LFRs). In this framework, the FRENETIC code for the multi-physics (neutronic + thermal-hydraulic) modeling of LFRs, previously developed at Polito, has been applied to the ALFRED reactor design. Calculations show very good agreement with reference Monte Carlo neutron transport calculations performed in Serpent. At the same time, the design of a code aimed at predicting the mass flow rate distribution and heat transfer in the gap between closed, hexagonal assemblies of ALFRED is ongoing. This activity will eventually lead, by the end of the Ph.D., to the development of a new computational tool for supporting the ALFRED design. Notably, the development is being carried out according to a clear software quality assurance plan.

The above-mentioned activities have been carried out in the framework of both national and international research projects, and the work has already been presented in several international conferences. In the next year the models developed will undergo further verification and validation, with the final goal of supporting the design of innovative nuclear reactor components employing LMs.

First name: Francesco **LAST NAME**: NEIROTTI

Topic: Decarbonization of Urban Areas: electrical and thermal grid integration

Course year: 1st **Tutor(s)**: Marco Simonetti, Michel Noussan

Academic context

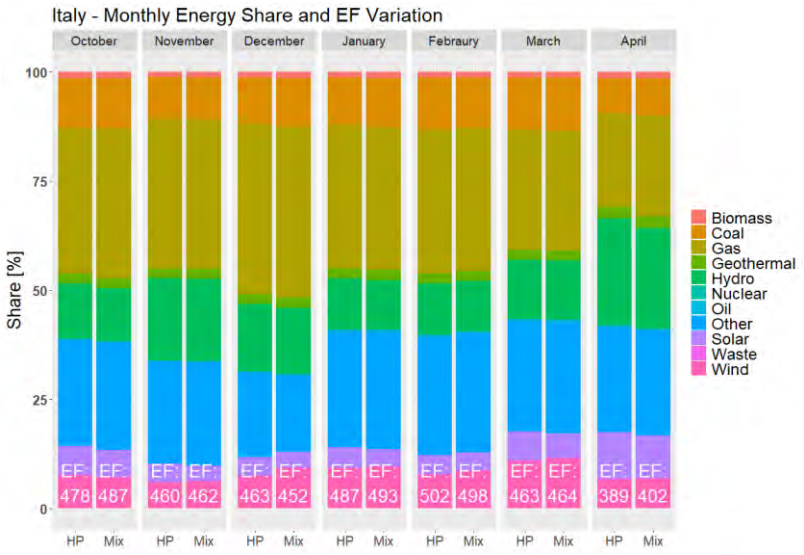
[1] Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, J., Hvelplund, F., & Mathiesen, B.V. (2014). 4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems. Energy, 68, 1-11. https://doi.org/10.1016/J.ENERGY.2014.02.089.
[2] Connolly, D. (2017). Heat Roadmap Europe: Quantitative comparison between the electricity, heating and cooling sectors for different European countries. Energy. https://doi.org/10.1016/j.energy.2017.07.037.
[3] Jarre, M., Noussan, M., & Simonetti, M. (2018). Primary energy consumption of heat pumps in high renewable share electricity mixes. Energy Conversion and Management, 171, 1339-1351. https://doi.org/10.1016/J.ENCONMAN.2018.06.067.

External collaborations

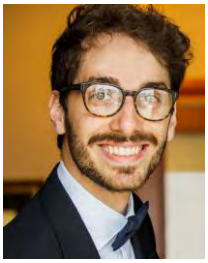
- Princeton University
- IEA Annex50 – Heat Pumps Technologies

Highlights of the research activity

Heat pumps (HP) technology, together with the interconnection of electrical and thermal grid, are the main drivers to decarbonize the urban areas and the heating and cooling sector. This first year as a PhD student has been focused on understanding the state of the art in the heating and cooling sector and the barriers to the diffusion of HP systems and the possible improvements for district heating (DH) system. If properly designed and managed, DH and HP can lead to CO2 savings as well as improve the overall efficiency of cities and communities. Through an LCA analysis, I've found that a DH impact could range from +72% to -60% with respect to distributed gas-fired boilers depending on the supply system and the allocation method used for the calculation. Nevertheless, the great capillarity of this technology could improve the waste heat recovery, especially if low operating temperatures are used. Similar behaviour has been studied for heat pumps looking at the electricity emissivity factor: it can be lower or higher than the national energy mix depending on when the system is used. This can lead to reduce the heating/cooling carbon emission or increase it if not well operated (**Figure 1**). On the other side, cooling systems can gain efficiency using adsorption cycles coupled with low-temperature DH, RES system and/or heat pumps. Based on this last topic, my research team and I joined the Re-Cognition EU project where we are developing a hybrid solar cooling system based on multiple thermal and sources, heat pumps and new adsorption material application. We started the prototype design phase with CFD simulation and investigation of new materials for cooling application.



Country Monthly emission factor variation against heat pump electricity consumption (Italy – 2018 data)



First name: Marco Savino **LAST NAME**: PISCITELLI

Topic: Energy management in buildings through data analytics technologies

Course year: 3rd **Tutor(s)**: Alfonso Capozzoli, Marco Perino

Academic context

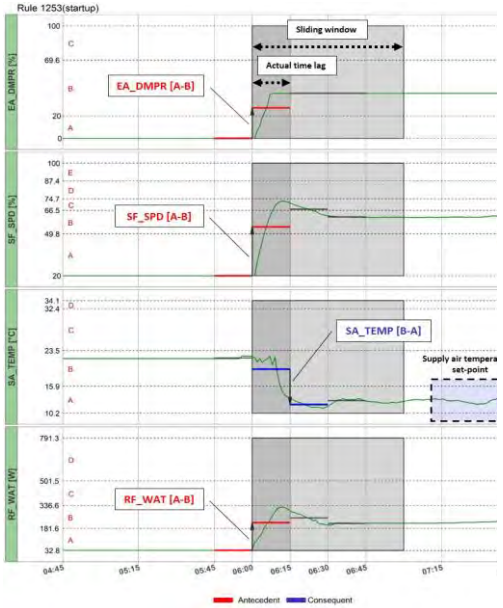
[1] Molina-Solana M, Ros M, Ruiz MD, Gómez-Romero J, Martín-Bautista MJ. Data Science for Building Energy Management: a Review. Renew Sustain Energy Rev 2017; 70: 598–609.
[2] Fan C, Xiao F, Madsen H, Wang D. Temporal knowledge discovery in big BAS data for building energy management. Energy Build 2015; 109: 75–89.
[3] Capozzoli A, Piscitelli M S, Brandi S., Grassi D., Chicco G. Automated load pattern learning and anomaly detection for enhancing energy management in smart buildings. Energy 2018; 157: 336-352.

External collaborations

- The Hong Kong Polytechnic University (PolyU)
- National University of Singapore (NUS)
- Università Federico II di Napoli (UniNa)

Highlights of the research activity

The energy management represents a fundamental task for effectively enhancing energy efficiency and reducing the mismatch between the actual and expected energy performance in buildings. In this context, advanced metering infrastructures are enabling the collection of a huge amount of building-related data, making the use of advanced analytics tools a very effective way for gaining robust insight on energy consumption patterns and driving the development of ready-to-implement energy conservation measures [1]. Particular attention has been devoted, during my PhD, to the branch of time series and temporal data analytics for conducting fault detection and diagnosis (FDD) analysis [2]. The main results of my research in this field concern with the development of FDD methodologies at both energy system and whole building level. In particular, thanks to the ensembling of innovative pattern recognition techniques and temporal association rules mining (***Fig.1***), a novel procedure has been developed for robustly detecting and diagnosing up to eleven different faults (related to the failure of fans, dampers and valves) by analyzing actual operational data of Heating Ventilation and Air Conditioning systems (HVAC). Further research has been conducted in this field also at a larger scale following a top-down approach (e.g., analysis of whole building energy consumption to discover abnormal energy system consumption). To this aim, a novel framework based on an effective transformation process of whole building energy consumption time series has been developed [3]. Data reduction, transformation and machine learning methods have been coupled and tested off-line on two different case studies to discover unexpected patterns in electrical energy consumption data. After a validation phase, the process has been implemented on a virtual server of Politecnico di Torino campus for working on-line.



Visualization of a temporal association rule used for detecting faults during the start-up period of an HVAC system

First name: Elisa **LAST NAME**: PRIMO

Topic: Actual energy performance and IEQ of buildings – the effect of occupancy

Course year: 3rd **Tutor(s)**: Vincenzo Corrado, Ilaria Ballarini

Academic context

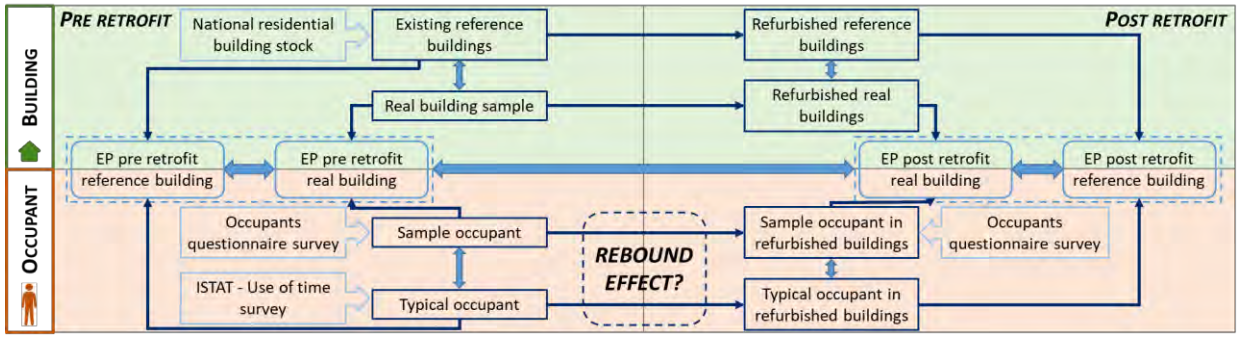
[1] Galvin R. Making the 'rebound effect' more useful for performance evaluation of thermal retrofits of existing homes: Defining the 'energy savings deficit' and the 'energy performance gap'. Energy and Buildings 69 (2014), 515-524.
[2] Guerra Santin O., Occupant behaviour in energy efficient dwellings: evidence of a rebound effect. Journal of Housing and the Built Environment 28 (2013), 311-327.
[3] Ben H., Steemers K. Household archetypes and behavioural patterns in UK domestic energy use. Energy Efficiency 11 (2018), 761-771.

External collaborations

- Technische Universität Wien (TU Wien, Austria)
- Italian National agency for new technologies, Energy and sustainable economic development (ENEA, Italy)
- Social housing agency of Central Piedmont (ATC Piemonte Centrale, Italy)

Highlights of the research activity

The occupant behaviour has great influence on the building energy consumption and several studies analysed its deviation in different households; anyway, the extent of such deviation is seldom quantified, as well as the effect of the variation of the user behaviour after the building retrofit. Within this research context, my activity introduces a preliminary analysis to improve the evaluation of energy savings in Italian building stock and to investigate the "rebound effect" in Italian retrofitted residential buildings.



Overall methodological framework of the Ph.D. activity

First of all, on the basis of literature, the activity has examined the influences of occupant behaviour on the energy savings for some residential reference buildings, representative of the Italian building stock. Some typical use patterns are defined according to statistics of the national census of population and dwellings and the expectations of the building occupants are specified before and after the retrofit.
Then, for some building types and energy efficiency measures, typical occupancy patterns are evaluated in real residential buildings. For the aim of the activity, a detailed questionnaire about households behaviour has been developed and it has been distributed to building occupants. The typical residential occupancy patterns resulting from the questionnaire survey are implemented in the dynamic simulation models for selected Italian case studies. On this basis the actual energy performance of case studies are assessed by calibrating the energy models by means of the monitored energy consumption.
The main outcome is the elasticity of the energy consumption in function of the occupancy parameters before and after the application of high energy efficiency improvements.

First name: Mamak **LAST NAME**: POURABDOLLAHTOOTKABONI

Topic: Towards energy efficient and heat-wave resilient buildings; A comparative study on energy related components, adaptation strategies and whole building performance

Course year: 1st **Tutor**: Vincenzo Corrado

Academic context

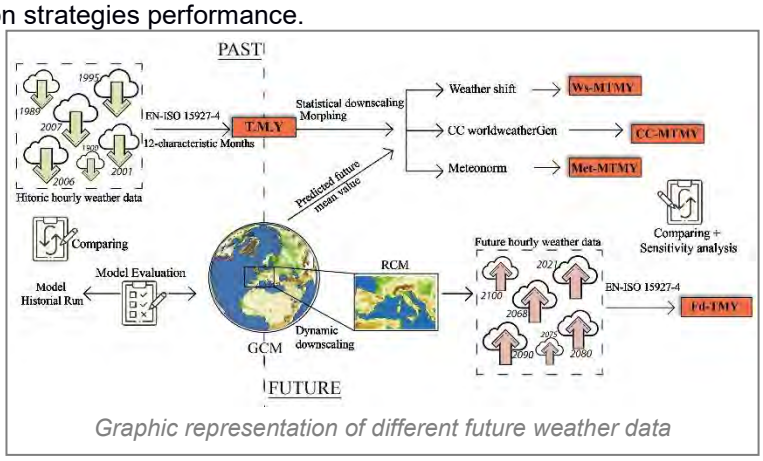
[1] Porritt, S. M., Cropper, P. C., Shao, L., & Goodier, C. I. (2012). Ranking of interventions to reduce dwelling overheating during heat waves. Energy and Buildings, 55, 16-27.
[2] Moazami, A., Nik, V. M., Carlucci, S., & Geving, S. (2019). Impacts of future weather data typology on building energy performance–Investigating long-term patterns of climate change and extreme weather conditions. Applied energy, 238, 696-720.
[3] Peacock, A. D., Jenkins, D. P., & Kane, D. (2010). Investigating the potential of overheating in UK dwellings as a consequence of extant climate change. *Energy policy*, *38*(7), 3277-3288.

External collaborations

- Institute of building research & innovation, Vienna, Austria (Operating agent of IEA EBC-Annex 80)

Highlights of the research activity

The main objective of this research project is investigating and optimizing energy performance and thermal comfort of buildings in case of summer heat waves, in order to avoid overheating issue and raises in energy consumption. Recent studies reveal that climate change has doubled the probability of the European heatwaves. The climate change projections express that such events will occur as often as each year by the middle of this century as the climate pattern has been disrupted. One of the major problems caused by the heatwaves is overheating of buildings, which leads to a significant raise in the cooling energy consumption and energy shortage . This trend seems to be inexorable and there has been increasing evidence pointing to the need for more holistic approaches (IEA EBC-Annex 80). During the first year of PhD, a considerable amount of literature has been reviewed to identify the frameworks for adaptation and resilience to changing climate, focusing on: Development of future climatic data, Analysing the impact of climate change on building performance and Evaluation of the adaptation strategies performance.



Graphic representation of different future weather data

For assessing and developing an adaptation framework, the fundamental prerequisite is getting known to the future climate variations. In this context, the first-year activity was also aimed at presenting a comparative study on different future climate data. The analysis of future climate is based on future scenarios, and the projections of climate models. "Representative Concentration Pathways (RCPs)" series of emission and concentration scenarios (IPCC 5th report), were selected to be used in this study. These scenarios are the input data used to provide initial conditions for Global Climate Models (GCMs), which are models for forecasting climate change. The GCMs have coarse spatial resolution and should be downscaled to be applicable for building energy simulation. Dynamic, stochastic and morphing downscaling methods were implemented and different future weather data were constructed for Milan (Italy) for less optimistic scenario, RCP8.5. A sensitivity analysis of various generated files is done with the aim of choosing the most reliable data set for representing the future condition. The next steps will be categorizing cooling strategies and solutions followed by comparative analysis of them, using appropriate key performance indicators (KPIs) and multidisciplinary evaluation matrix.

First name: Sofia **LAST NAME**: RUSSO

Topic: Exergoeconomic analysis and optimization under uncertainty of Solid Waste treatment plants

Course year: 2nd **Tutor**: Vittorio Verda

Academic context

[1] Andreasi Bassi, S., Christensen, T. H., Damgaard, A. (2017). Environmental performance of household waste management in Europe – An example of 7 countries. Waste Management, 69, 545-557
[2] Maqsood, I., Huang, H. G., (2012). A Two-Stage Interval Stochastic Programming Model for Waste Management under Uncertainty. Air & Waste Management 53, 540-552
[3] Stanek, W., Valero, A., Valero, A., Uche, J., Calvo, G. (2017).Thermodynamic Methods to Evaluate Resources. Thermodynamics for Sustainable Management of Natural Resources, Chapter 6, Springer

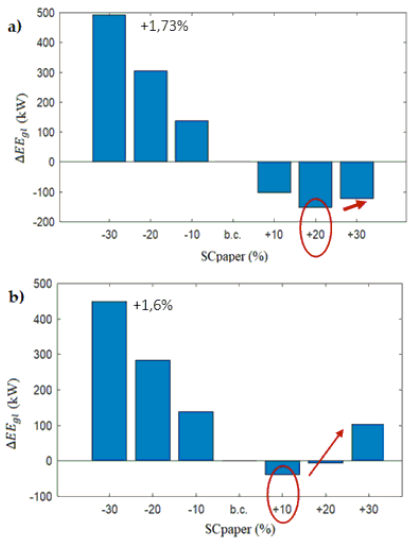
External collaborations

- Research Centre for Energy Resources and Consumption (CIRCE), University of Zaragoza ,Spain

Highlights of the research activity

Solid Waste Management (SWM) is still a crucial issue for European countries. The development of an Integrated SWM system is strongly influenced by social, political and economic elements, which entail a high degree of uncertainty. The general objective of this research project is to use exergy criteria to propose optimal management strategies for the allocation of the material streams into the SW treatment systems, according to the variety of operating conditions that can occur. For this reason, stochastic tools are adopted for generating simulation scenarios. The instruments of Exergoeconomics are used, since exergy is used as a rational basis to compare flows of different nature (material and non-material). In a system-based analysis, a modelling and simulation of a Mechanical Biological Treatment (MBT) plant of unsorted Municipal Solid Waste (MSW), for Refused Derived Fuel (RDF) production was performed. A crude Monte Carlo method was used to sample from uniform distributions of degree of Selective Collection (SC) for single material stream, for reproducing the randomness in unsorted waste composition. The equipment energy consumption was considered as the internal uncertain variable. The results confirmed the primary influence of the external uncertain variables over the internal ones. The analysis was then extended by including the paper recycling chain in the MSW treatment system. In this case, the concept of Embodied Exergy (EE) was used to account for the avoided or additional exergy in different scenarios of SC. The exergy cost of MSW collection, process and transport of raw materials (wood for virgin cardboard production, coal for substituting RDF fuel) are included in the global EE balance, in addition to the contribution of the single treatment process. Results showed that, in general, a decrease in SC of paper leads to greater savings in global EE, but this effect diminishes for high collection of paper, because of the influence of MSW transport and coal cost.

In a material-based analysis**,** exergy is also used for comparing the resources invested in producing polymers from primary (virgin) material with those from secondary materials through recycle. The production routes were established according to the 'grave to cradle' path (including polymerization, oil derivatives production and fossil fuel extraction) and the thermodynamic rarity is calculated. In order to evaluate the recycling process, exergy-based recycling indexes are developed depending on the final product (e.g. the new crude polymeric material or the oil derivatives). The next steps of the project will include the development of an optimization model accounting for the uncertainty in the entire treatment system.



Differences in global EE for a) fixed cardboard production and b) fixed MBT inlet and cardboard production

First name: Francesco **LAST NAME**: SAPIO

Topic: Diesel after-treatment modelling optimization techniques

Course year: 3rd **Tutor(s)**: Federico Millo

Academic context

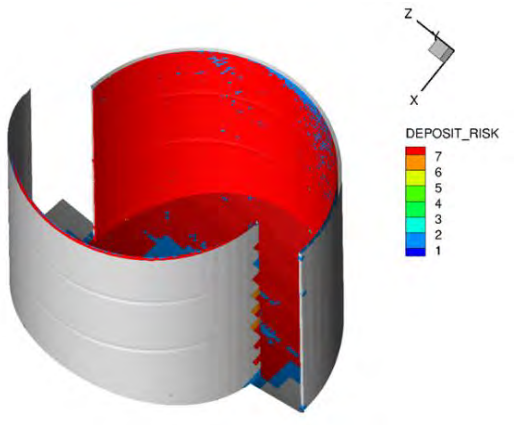
[1] Gundlapally, S.R., et al. "Development of ECU Capable Grey-Box Models from Detailed Models-Application to a SCR Reactor," Emiss. Control Sci. Technol., 2016, doi:10.1007/s40825-016-0039-x.
[2] Millo, F., Rafigh, M., Sapio, F., Barrientos, E.J., and Ferreri, P., "Application of Genetic Algorithm for the Calibration of the Kinetic Scheme of a Diesel Oxidation Catalyst Model," 2018, doi:10.4271/2018-01-1762
[3] Millo, F., Rafigh, M., Sapio, F., Wahiduzzaman, S., Dudgeon, R., Ferreri, P., and Barrientos, E., "Modeling NOx Storage and Reduction for a Diesel Automotive Catalyst Based on Synthetic Gas Bench Experiments," Ind. Eng. Chem. Res. 57(37):12335–12351, 2018, doi:10.1021/acs.iecr.8b01813

External collaborations

- General Motors Global Propulsion Systems
- Gamma Technologies
- Cornaglia Group

Highlights of the research activity

A growing concern about global warming and pollutants effects on human health is pushing the world towards more stringent regulations for the transportation sector. The introduction of more aggressive driving cycles and rigorous limits on pollutants emissions represent a crucial challenge for the automotive industry, which is called to simultaneously decrease fuel consumption and engine emissions. Therefore, to ensure compliance with emissions regulations, especially regarding NOx, robust and efficient AftertTreatment (AT) architectures are mandatory. In this framework, the combined employment of experimental and numerical analysis demonstrated its effectiveness in supporting the aftertreatment systems development.
During an internship in Gamma Technologies USA, I participated at the development of zero-dimensional reduced order models for real time and ECU-ready simulations. As a result of this activity, a grey-box model of an SCR catalyst has been developed, which includes two different ammonia desorption sites and side reactions such as the formation of ammonium nitrate. Such models can effectively support the development and the optimization of control strategies for aftertreatment architectures, due to the minimum computational effort required, but their accuracy is limited in a narrow range. To investigate thermal and fluid dynamics effects in complex geometries, a more detailed approach is required. In such context, a comprehensive work was carried out in cooperation with Cornaglia Group to fully characterize 2 latest generation AT systems. An experimental campaign was conducted in order to identify the relevant physical-chemical properties of each system, while 3D CFD numerical simulation was used to compare the different designs in terms of introduced pressure drop, flow and species uniformity, induced turbulence level, amount and area of liquid film formed, risk of urea deposits as shown in Figure 1. This approach demonstrated its effectiveness in analyzing complex large-dimensional problems, although requesting a large amount of resources. As part of the partnership with General Motors, I'm currently working at the development and optimization of 1D CFD models of complex exhaust lines, including several catalysts and flow components, for HiL and and real time simulations. Such model can be applied for the virtual calibration of new AT layouts, to asses the capabilities of newly developed engines to fulfill emissions regulations, to develop and optimize control strategies.



Preliminary assessment of solid deposits formation risk, 1 indicates the lowest risk level, 7 refers to the highest.

First name: Daniele Salvatore **LAST NAME**: SCHIERA

Topic: Energy planning in the urban context: integrating planning and operational dimensions

Course year: 1st **Tutor(s)**: Romano Borchiellini, C. Cambini

Academic context

[1] D. S. Schiera, F. D. Minuto, L. Bottaccioli, R. Borchiellini and A. Lanzini, "Analysis of Rooftop Photovoltaics Diffusion in Energy Community Buildings by a Novel GIS- and Agent-Based Modeling Co-Simulation Platform," in IEEE Access, vol. 7, pp. 93404-93432, 2019, doi: 10.1109/ACCESS.2019.2927446.
[2] Wetter, Michael, and Christoph van Treeck. "IEA EBC Annex 60: New Generation Computing Tools for Building and Community Energy Systems." The Regents of the University of California and RWTH Aachen University (2017).
[3] M. Uslar et al., “Applying the Smart Grid Architecture Model for Designing and Validating System-of-Systems in the Power and Energy Domain: A European Perspective”, Energies, vol. 12, n. 2, pag. 258, gen. 2019.

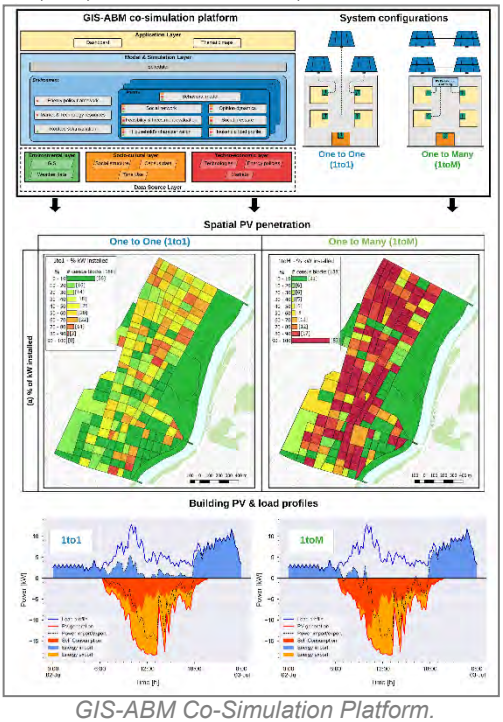
External collaborations

- Edison, Italy

Highlights of the research activity

The research focues on developing a holistic approach for energy planning and operational dimensions with the main purpose of pushing the communities towards the smart, efficient and rational management of energy. Moreover, the project could be framed as a synergic investigation of the Sustainable Development Goals 7 and 11.

This first PhD year was dedicated to acquiring the knowledge on multi-energy systems and sustainable energy conversion systems in all their facets. Meanwhile, in order to acquire a multi-perspective view on urban communities, it has been of great importance to study related topics, i.e, microeconomics, socio-economic theories, behavioral barriers, urban development, and energy policy strategies. Furthermore, attention has been given to study programming languages, software development, and co-simulation techniques for energy systems modeling, energy scenario making and analysis. These preliminary studies led to my first journal publication [1], with a work dealing with the development of a model to assess the spatial and temporal PV diffusion across households at the urban scale using a georeferenced agent-based approach and co-simulation techniques. The model was used to evaluate a policy scenario based on the Local Energy Communities represented by condominiums, where residents can install a shared rooftop PV system, and compare it with the business as usual one, where only single households can install a rooftop PV. This work has been fundamental as a preliminary study of the main research activity of the Energy Center Lab research group, which is the development of a comprehensive methodology for the study of urban sustainable communities based on a multi-modeling and co-simulation techniques. In this context, further research will be carried out on the formalization of a first case study of the platform, aiming to look inside a building and model the components of each functional layer using different modeling techniques and make them connected to each other through the co-simulation platform.



GIS-ABM Co-Simulation Platform.

First name: Stefano **LAST NAME**: SEGANTIN

Topic: Materials, design and safety of high field D-T fueled tokamaks

Course year: 1st **Tutor(s)**: Massimo Zucchetti, Raffaella Testoni

Academic context

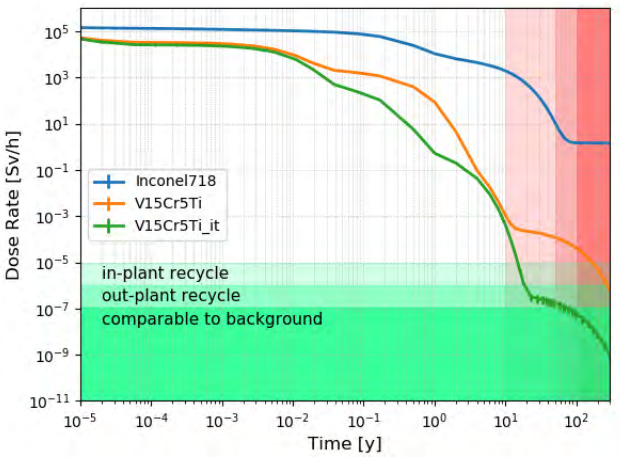
[1] Sorbom, B. N., et al. "ARC: a compact, high-field, fusion nuclear science facility and demonstration power plant with demountable magnets." Fusion Engineering and Design 100 (2015): 378-405.
[2] Segantin, S., et al. "Exploration of a Fast Pathway to Nuclear Fusion: Thermal Analysis and Cooling Design Considerations for the ARC Reactor." Fusion Science and Technology (2019): 1-8.
[3] Segantin, S., et al. "The lifetime determination of ARC reactor as a load-following plant in the energy framework." Energy policy 126 (2019): 66-75.

External collaborations

- Massachusetts Institute of Technology (MIT) - Cambridge, MA, US
- ENI – San Donato Milanese (MI), Italy

Highlights of the research activity

Activities of the first PhD year focused on engineering aspects and radioactive inventory reduction of the Affordable Robust Compact (ARC) reactor, a high magnetic field tokamak designed and proposed by MIT's Plasma Science and Fusion Center.
In this framework, the inventories of tritium and the activated materials have been evaluated and a reduction strategy has been developed and applied. It came out that it is possible to reduce by applying on the structure a "low activation alloy" based on V-Cr-Ti, in substitution of the previously applied Ni-based Inconel 718 structure. Hence, the work focused on proposing and modeling a reactor's vacuum vessel based on the mentioned material. For the purpose, in order to evaluate the tritium breeding ratio (TBR) of the new core configuration, a neutron transport model has been developed. The new structure is able to increase the TBR by about 10%, reducing the total tritium inventory that is inversely proportional to such parameter. In addition, the new structure allows removing hazardous components such as beryllium layers, previously applied for neutron multiplication purposes.
The study continued by developing a neutron activation model aimed to carry out an inventory analysis of the new core configuration. In this respect, optimization techniques, such as isotopic tailoring and material detritiation, have been applied. A vacuum vessel based on optimized V-Cr-Ti alloys and exposed to ARC's core condition could virtually be recycled within the nuclear industry after a couple of decades of cooling time. The previous configuration, which was based on the Inconel 718 material, could not achieve such goal within 100 years of cooling time.
A further activity performed a starting study for ARC's power conversion system. The study analyzed several different thermodynamic cycles, each of the cycles optimized by a Python algorithm. Results shown that a regenerative carbon dioxide Brayton cycles achieves the best performances by far, in ARC's temperature range. In particular, depending on the pressures and temperature, the thermodynamic efficiency has been found equal to 0.5-0.6 while requiring components four times more compact than any other cycle.



Contact dose rate vs. cooling time of low activation ARC's vacuum vessel

First name: Alicia **LAST NAME**: SOTO

Topic: Carbon capture utilization and storage (CCUS) and how to accelerate the commercialization of carbon-based products

Course year: 3rd **Tutor(s)**: Massimo Santarelli, Ignasi Casanova (UPC)

Academic context

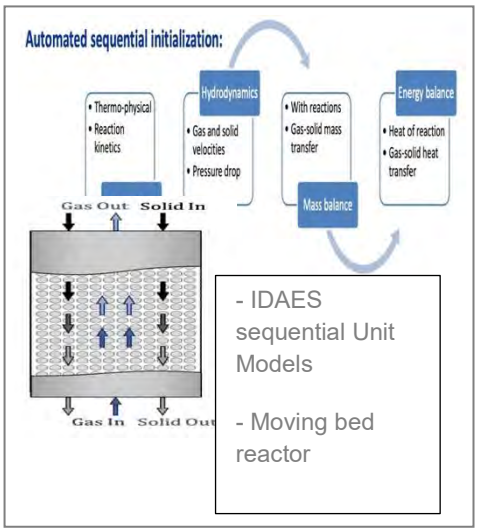
[1] Parigi D., Giglio E., Soto A., Santarelli M., Power-to-fuels through CO2 utilization and high-temperature electrolysis: A technical and economical comparison between synthetic methanol and methane, Journal of Cleaner Production, Volume 226, 20 July 2019, Pages 679-691.
[2] Gandiglio M., Lanzini A., Soto A., Leone P., Santarelli M., Enhancing the energy efficiency of wastewater treatment plants through co-digestion and fuel cell systems, Frontiers in Environmental Science, Volume 5, 30 October 2017, Article number 70.
[3] Wei, Z., Wang, B., Falzone, G., La Plante, E. C., Okoronkwo & Sant, G. (2018). Clinkering-free cementation by fly ash carbonation. Journal of CO2 Utilization, (December 2017), 117–127. https://doi.org/10.1016/j.jcou.2017.11.005

External collaborations

- NETL Institute for the Design of Advanced Energy Systems (IDEAS) funded by the US Dept. of Energy, Pittsburg, PA
- Universitat Politecnica de Catalunya (UPC), Barcelona Tech., Spain
- University of California, Los Angeles (UCLA)

Highlights of the research activity

The research consists of a two-pronged approach. First; the capacity of the understanding of the whole chain of CCUS process by the development of a mathematical model using the newly developed IDAES open source modeling tool. The software allows for the design and optimization of transformational CO_2 capture technologies such as the one I have developed of a moving bed reactor. The reactor facilitates the chemical process of direct mineral carbonation between the CO_2 contained in the flue gas and high-calcium fly ash, two underutilized byproducts formed at coal power plants. The aim is to manufacture carbonated fly ash, a commodity that can permanently capture CO_2 but also has the benefit to be a complementary cementitious material used in the construction Industry. The reactor has been designed as a modular, true scale addition that can be installed within the premises of the power plant, preferably near the raw sources to eliminate any transportation cost.



The second approach of my research addresses the identification of business opportunities for CCUS technologies and carbon-based products that yield an attractive ROI. The research will employ a qualitative study methodology by adopting an exploratory comparative case study to develop a
better perception of the enablers and barriers to technology commercialization of CCUS in the concrete/construction. industry.
Moving forward, the work will focus on the completion of the following tasks:

(1) Finalize a techno-economic analysis with the intent of producing a technical paper for publication.
(2) Develop an entrepreneurship/business paper that will incorporate the newly developed technical aspects.
(3) Finalize a paper focusing on the analysis of policy, standards, and regulations related to the use of fly ash in the construction industry.

First name: Alessandro **LAST NAME**: TANSINI

Topic: Road vehicles CO_2 flexible calculation approaches

Course year: 3rd **Tutor(s)**: Federico Millo

Academic context

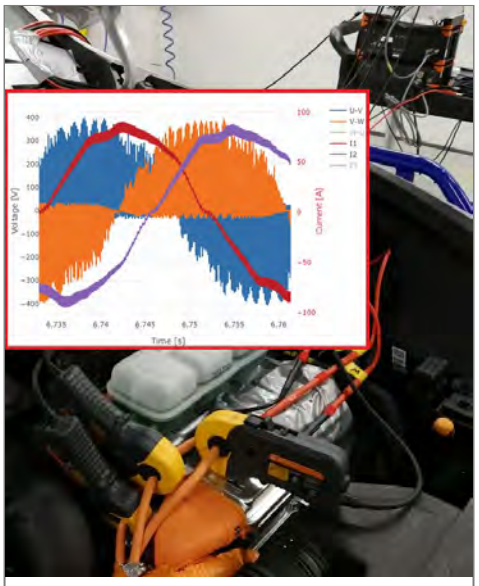
[1] A. Tansini, G. Fontaras, B. Ciuffo, F. Millo, I. Prado Rujas and N. Zacharof; "Calculating Heavy-Duty Truck Energy and Fuel Consumption Using Correlation Formulas Derived From VECTO Simulations"
[2] S. Doulgeris, A. Tansini, A. Dimaratos, G. Fontaras, Z. Samaras; "Simulation-based assessment of the CO_2 emissions reduction potential from the implementation of mild-hybrid architectures on passenger cars to support the development of CO2MPAS"
[3] G. Di Pierro, F. Millo, A. Tansini, G. Fontaras, M. Scassa; "An Integrated Experimental and Numerical Methodology for Plug-In Hybrid Electric Vehicle 0D Modelling"

External collaborations

- European Commission's Joint Research Centre
- Aristotle University of Thessaloniki – Laboratory of Applied Thermodynamics
- FEV Italy

Highlights of the research activity

The calculation tool CO2MPAS developed by the European Commission handles the conversion of the WLTP-based CO_2 emissions from the certification procedure into the NEDC-equivalent emissions (the so-called *correlation*) for the compliancy check with 2020 targets. The conversion of the CO_2 emissions into NEDC-equivalent values is necessary until the end of 2020, when the NEDC will definitely be replaced by the WLTP; after that, new WLTP-based CO_2 targets will be set and no correlation tool will be needed. Anyhow, CO2MPAS will likely be used after 2020 to support the European Commission in the policy making process. For this reason, it was necessary to keep the tool updated with the latest powertrain technologies and control strategies; to this aim, it was crucial to implement the necessary models and control strategies to cover electrified powertrains. Literature review was conducted to identify the most relevant hybrid electric architectures for Light-Duty Vehicles applications. Several vehicles were tested in the VELA laboratories of the JRC and on the road to collect data and get understanding of the control strategies; the data was also used to derive indicative efficiency values/functions for the components.
I was responsible for vehicle instrumentation and testing for the characterisation of the hybrid powertrain operation; the normal chassis dynamometer measurements were complemented with OBD data (standard + extended PIDs), CAN data and power analyzer electrical measurements (see the figure) to get a complete picture of the operation. In addition to testing, data collection and post-processing, I also developed a simulation strategy for hybrid electric powertrains, with the goal of replicating the operating conditions and therefore the fuel efficiency. The model is structured in levels: a supervisory controller (to handle the out-of-design operation), an internal combustion engine manager (to deal with powertrain limitations and dynamics) and an optimiser (to choose the optimal solution among the ones that were not excluded by the upper levels). When the strategy proved to be mature enough, we implemented it into CO2MPAS. The latest release of the tool (31st October 2019) therefore contains a basic strategy for hybrid vehicles simulation. Efforts still have to be made in order to make the model complete and accurate, getting satisfactory results for the main architectures (parallel, serial, power split).



3-phase AC motor power measurement

First name: Valeria **LAST NAME**: TODESCHI

Topic: Smart energy solutions for sustainable cities and policies

Course year: 1st **Tutors**: Guglielmina Mutani, Marco Masoero

Academic context

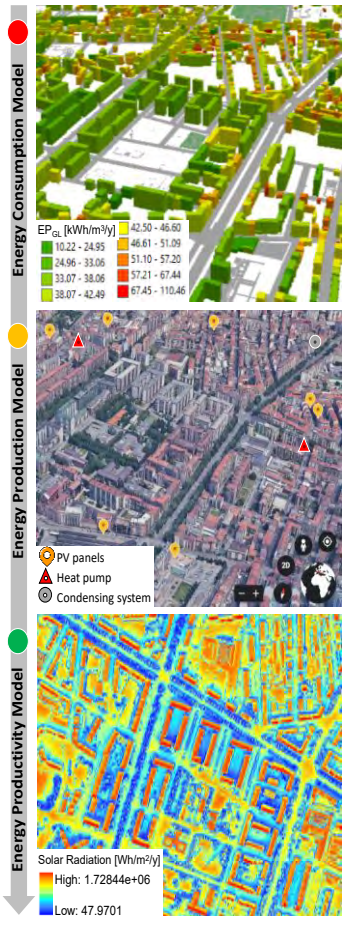
[1] Mutani, G., Todeschi, V., "Energy Resilience, Vulnerability and Risk in Urban Spaces", JSDEWES, 6 (4), 694-709 (2018) doi:10.13044/j.sdewes.d6.0203.
[2] Guelpa, E., Mutani, G., Todeschi, V., Verda. V., "Reduction of CO_2 emissions in urban areas through optimal expansion of existing district heating networks", J. Clean. Prod., 204 (2018) doi:10.1016/j.jclepro.2018.08.272.
[3] Mutani, G., Todeschi, V., Coors, V., Kaempf, J., Fitzky, M., "Building energy consumption modeling at urban scale: three case studies in Europe", INTELEC®, Turin (IT), October 2018, doi:10.1109/INTLEC.2018.8612382.

External collaborations

- Joint Research Centre (JRC), Ispra (VA), IT
- Stuttgart Technology University of Applied Sciences (HFT), DE
- Ecole Polytechnique Fédérale de Lausanne (EPFL), CH

Highlights of the research activity

The reduction of energy-use in buildings could be one of the main drivers to improve the energy sustainability and quality of urban environment, exploiting the production of energy from available renewable sources [1]. The development of Urban-Scale Energy Modelling (USEM) is currently the goal of many research groups due to the increased interest in evaluating the impacts of energy efficiency measures in cities. These models are useful to explore consumptions and emissions distribution at district scale and to quantitatively assess retrofit strategies and energy supply options, leading to more effective energy and environmental policies [2]. Since the relation between urban form and buildings affects their energy performances, with USEMs it is possible to obtain lower energy demand by improving the morphology of the built environment. The novelty of USEMs is that a number of variables can be added to the energy balance to take into account, for example, the urban context: i.e. solar exposition, urban canyon height to distance ratio, presence of vegetation, characteristics of outdoor spaces [3]. Up to now, USEMs only consider few variables that influence consumptions, especially as regards the urban context. The aim of this research is to investigate the following topics: i) At territorial scale, USEMs manage a large number of data with low detail and different scales but high accuracy and low simulation times are required. ii) Can the use of urban parameters improve the precision of USEMs with a flexible and easily approach that may be applied to different contexts? iii) Can USEMs help policy makers, local authorities and citizens in the reduction of energy consumptions or emissions giving information at different scales (from territorial, to a district/municipal or a building scale)?. An 'engineering' model was developed for some cities (Turin in **Errore. L'origine riferimento non è stata trovata.**) in order to create an urban energy atlas for the building stock with the support of Geographical Information System (ArcGIS 10.7) and Google Earth tools. The aim is to create a platform to help stakeholders, urban planners and policy makers to plan sustainable cities and smart energy systems, and to obtain information, at different scales, about energy consumptions, production and emissions. With this engineering model, it is also possible to evaluate how energy consumption changes according varying buildings' energy efficiency level and system efficiencies, but also the urban morphology. The goal is to guarantee energy security, affordability and environmental sustainability for more resilient cities.



Urban Scale Energy Modeling: an example of the city of Turin (IT)

First name: Blessing Onyeche **LAST NAME**: UGWOKE

Topic: Integrated Rural Energy Planning (IREP)

Course year: 3rd **Tutor(s)**: Stefano Corgnati, Leone Pierluigi

Academic context

[1] Szabó S., Moner-Girona M., Kougias I., Bailis R., Bódis K. (2016) Identification of advantageous electricity generation options in sub-Saharan Africa integrating existing resources. NATURE ENERGY.
[2] Colombo E., Leone P., Taisch M., Cheli F.; Pinzone M.; Arrigoni A.; Chiasserini C.F, Boccardo P. (2017) Toward Smart and Integrated Infrastructure for Africa: An Agenda for Digitalization, Decarbonisation and Mobility Infrastructure Consortium for Africa. G7 INFRASTRUCTURE CONSORTIUM FOR AFRICA-BACKGROUND PAPER.
[3] Corgnati S.P., Fabrizio E., Filippi M., Monetti V. (2013) Reference buildings for cost optimal analysis: Method of definition and application. APPLIED ENERGY.

External collaborations

- Eni S.p.A
- Italian Ministry of Foreign Affairs and International Cooperation

Highlights of the research activity

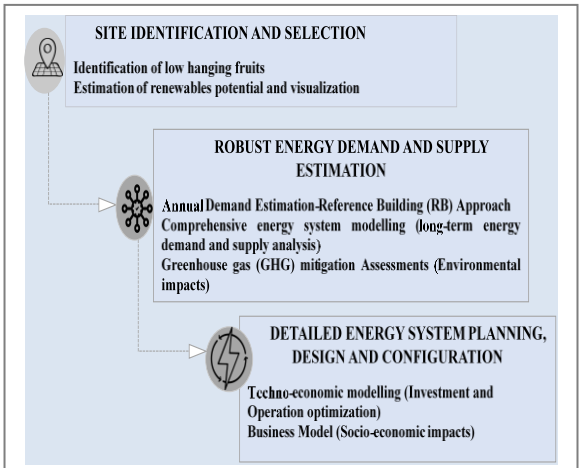
The overall objective is to proffer a holistic, integrated and strategic energy system planning framework/ road map to better inform the decision making of stakeholders, policy makers and investors in the energy industry of Nigeria with focus on rural communities to achieve sustainable development. The methodology proposed for the bottom-up electrification of rural settlements entails locating, planning and operating standalone microgrids for rural applications in Nigeria, thus developing a unified framework/road map for rural electrification in Nigeria. The methodology comprises three broad steps from 1) site identification and selection through 2) robust energy demand and supply estimation 3) detailed energy system configuration.

At the end of the second year, research activities conducted have been mainly focused on the first and second broad steps of the framework.

Firstly, by building upon the integrated low hanging fruit approach proposed by Szabo et.al. where the potential of existing energy infrastructure is analyzed and a significant upfront investment has already been made, suitable locations were identified and selected.

Secondly, having identified the target locations, their potential for exploitation was then estimated using the methodology reported in IRENA, Mentis et al. and Gomez et al.

Thirdly, robust and targeted energy demand estimation was carried out using the reference building approach which employs reference building models as characteristic and representative buildings in terms of functionality and geographic location of a building stock, including internal and external environmental condition.



IREP Framework

Fourthly, using the LEAP energy system model, the plausible evolution of the demand has been forecasted. The technology alternatives for energy supply have been analyzed by means of integrated social cost-benefit analysis and least-cost optimization approach. The environmental loadings for the different supply technologies have been calculated.

First name: Domenico **LAST NAME**: VALERIO

Topic: Multi-physics modelling of liquid metals in Advanced Nuclear Systems

Course year: 1st **Tutor(s)**: Sandra Dulla, Laura Savoldi (until Oct. 2nd, 2019), Roberto Bonifetto (since Oct. 2nd, 2019)

Academic context

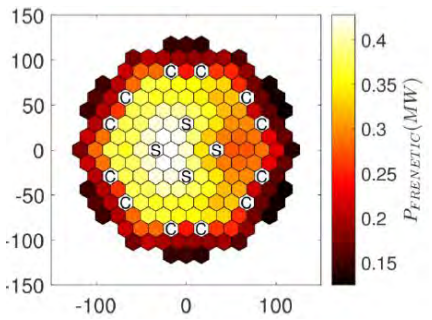
[1] R. Bonifetto, A. Bertinetti, A. Froio, L. Savoldi, M. Utili, D.Valerio, R. Zanino. Conceptual design of a mock-up for the EU DEMO Tritium Extraction System based on Permeator Against Vacuum technology, 12th International Conference on Tritium Science and Technology, April 22-26, 2019
[2] D. Valerio, R. Bonifetto, L. Savoldi, M. Utili, R. Zanino. Design of the EU DEMO Tritium Extraction System mock-up based on Permeator Against Vacuum technology, 14th ISFNT, Budapest, September 22-27, 2019
[3] G.F. Nallo, N. Abrate, S. Dulla, P. Ravetto, D. Valerio. Neutronic benchmark of the FRENETIC code for the multi-physics analysis of lead fast reactors, The European Physical Journal Plus, in press, 2019

External collaborations:

- ENEA Brasimone
- EUROfusion

Highlights of the research activity

The research activities foreseen in the PhD. project address the multi-physics modeling of the liquid metals in both fusion and fission nuclear systems. In particular, the work on fusion topic is related to the Tritium Extraction Systems (TES) in the fuel cycle of the EU DEMO reactor, whereas for the fission field the focus is on the analysis (and optimization) of liquid-metal cooled fast reactors performed by the FRENETIC code.
The first part of the fusion activities has been carried out on the large-scale TES of the EU DEMO reactor, for the option based on the permeator-against-vacuum (PAV) technology. The task was to design the permeator membrane (pipes in which the liquid PbLi with dissolved tritium flows) to get the desired efficiency of tritium extraction: two materials (Nb and Fe) have been investigated as alternative options, and this work has been presented at TRITIUM 2019 [1] (South Korea). Starting from an existing diffusion-limited model for the tritium permeation, a new model has been developed, where also superficial membrane phenomena are taken into account, based on a suitably-modified version of the theory of Pick and Sonnenberg. This new model is being used to design a sub-size PAV mock-up to be tested next year at ENEA Brasimone premises in TRIEX-II facility. The purpose of the test will be the measurement of the extraction efficiency for the calibration and validation of the new permeation model. The preliminary mock-up design has been presented at ISFNT 14 in Budapest [2].
The fission activities have been almost completely focused on the case study of the lead-cooled reactor named ALFRED. In order to complete the validation of the coupled neutronic/thermal-hydraulic FRENETIC code, a preliminary comparison between the steady state power distributions calculated by the Monte Carlo transport code Serpent (taken as reference) and FRENETIC has been performed (See Figure). Results show an excellent agreement on the power distribution [3]. The FRENETIC code has been extended to manage the entire geometry of the reactor: the major improvement is in the thermal-hydraulic module where the capabilities of modeling the coolant outside the core has been implemented. To complete the multi-physics tool validation including the neutronic physic, a simulation with another experimental case is foreseen. The sodium cooled reactor EBR-II was part of an international benchmark of IAEA to demonstrate the capabilities of the actual tools to reproduce the behavior of a Loss-of-flow-accident (LOFA) initiating event (IE), showing the effects of passive and inner safety measures in this kind of reactor. The thermal power deposited in cold assemblies due to n-gamma reactions and scattering events is not negligible, so if a thermal-hydraulics IE occurred (like a flow reduction, i.e. a LOFA), vaporization of the coolant would result. The simulation of such a transient will validate also the module describing photon transport, already implemented in FRENETIC. This work will be presented at PHYSOR2020 in Cambridge.



Reduction of thermal power distribution calculated by FRENETIC after the insertion of the safety rod in the ALFRED

First name: Oscar **LAST NAME**: VENTO

Topic: Fluid dynamics of internal combustion engines – Diesel injection systems

Course year: 2nd **Tutor(s)**: Alessandro Ferrari, Antonio Mittica

Academic context

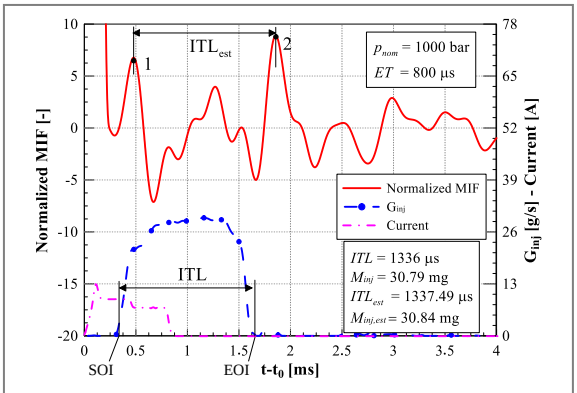
[1] A. Ferrari, C. Novara, E. Paolucci, O. Vento, M. Violante, T. Zhang, A new closed-loop control of the injected mass for a full exploitation of digital and continuous injection-rate shaping, Energy Conversion and Management, Volume 177, 1 December 2018, Pages 629-639.
[2] A. Ferrari, C. Novara, E. Paolucci, O. Vento, M. Violante, T. Zhang, Design and rapid prototyping of a closed-loop control strategy of the injected mass for the reduction of CO2, combustion noise and pollutant emissions in diesel engines, Applied Energy, Volume 232, 15 December 2018, Pages 358-367.
[3] A. Ferrari, F. Paolicelli, P. Pizzo, Hydraulic performance comparison between the newly designed common feeding and standard common rail injection systems for diesel engines. ASME J. Eng. Gas Turbines Power, 138, p. 092801.

External collaborations

- Nanyue Fuel Injection Systems Co., Ltd.

Highlights of the research activity

In this two years of PhD activity I worked in a Proof of Concept project about the design of a closed-loop control of the injected mass for diesel engines. The control was based on a measure of two pressure signals in the high-pressure pipe that connects the rail and the injector. After the hydrauluc characterization of the standard injection system, the innovative closed loop strategy for the injected mass control has been implemented in a rapid prototyping hardware. The hydraulic characterization of the injection system has been repeated in the presence of the innovative control strategy. The error in the actuated injected mass was found to be below 1 mg for all the working conditions for different fuel temperatures. Also for Pilot-Main injection, an improvement for all the dwell time range was appreciated, especially in the short one: in this case the error is passed from 10 mg to 2 mg. A different approach, based on the time frequency analysis, has also been developed to obtain the feedback signal for the control of the injected mass. A “virtual sensor” of the injector needle is realized, which is able to detect when the injection starts and ends and so the injection temporal length (ITL) can be evaluated. This has been done by analyzing the mean instantaneous frequency of the pressure signal measured at the injector inlet. Thanks to this information the injected mass can be predicted by using the nominal pressure-ITL correlation that is independent of the fuel temperature instead of the common energizing time-nominal pressure correlation that is usually dependent on the thermal regime. Another activity in which I was involved was related to the hydraulic characterization of a new type of injection system, called “Common Feeding”, featured by a strongly reduction of the rail accumulation volume. Nanyue FYS Co., Ltd has prepared some rails with different accumulation volumes and a pump with a small delivery volume where the injectors can be directly connected. Results leaded to say that, for a light duty vehicle, the no-rail configuration can keep the standard performance. I am performing a comparing analysis about the frequency dependent friction in the high-pressure circuit of a Common Rail system. The main objective of my work is to understand when the unsteady friction is necessary to be considered in numerical simulations of 1D pipes and how much it can improve the results, furthermore I compare the results of the various methods by using home-made and commercial numerical tools.



Injected flow-rate and the normalized MIF

First name: Loris **LAST NAME**: VENTURA

Topic: Development and assessment of model-based and sensor-based algorithms for air path, combustion and emission control in diesel engines.

Course year: 1ST **Tutor(s)**: Roberto Finesso, Stefano Malan and Stefano d'Ambrosio

Academic context

[1] Hu, S.; d'Ambrosio, S.; Finesso, R.; Manelli, A.; Marzano, M.R.; Mittica, A.; Ventura, L.; Wang, H.; Wang, Y. "Comparison of Physics-Based, Semi-Empirical and Neural Network-Based Models for Model-Based Combustion Control in a 3.0 L Diesel Engine". Energies 2019, 12, 3423. doi: https://doi.org/10.3390/en12183423
[2] L. Ventura, R. Finesso, S.A. Malan, S. d'Ambrosio and A. Manelli, "Model-based Design of Closed Loop Controllers of the Air-path in a Heavy Duty Diesel Engine", 2019, 74° Congresso Nazionale ATI, Modena, 2019. In press.
[3] S. A. Malan and L. Ventura, "Air-Path Control for a Prototype PCCI Diesel Engine", 2018 26th Mediterranean Conference on Control and Automation (MED), Zadar, 2018, pp. 843-848. doi: 10.1109/MED.2018.8442647

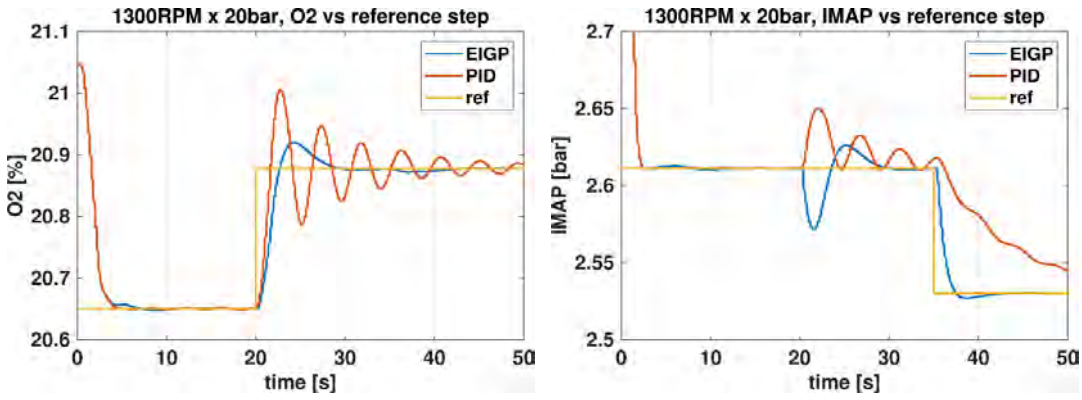
External collaborations

- FPT Motorenforschung AG

Highlights of the research activity

My research activity is focused on development and assessment of model-based and sensor-based algorithms for air path, combustion and emission control in diesel engines. My first year activity was mainly focused on a preliminary identification and study of the air path controller. This controller will be tested on a 2.3L FPT diesel engine that is currently being installed at the dynamic test bench of Politecnico di Torino, within a research project in collaboration with FPT Industrial. The preliminary development of the controller was carried out on the basis of 5 activities, which are described hereafter:

1. Investigation of input-output (black box) models for the air-path of diesel engines;
2. Development of a test procedure in order to collect the data needed to the identification process of the black-box models. The procedure has been automated through AVL CAMEO;
3. Experimental test analysis to derive correlations between variables involved in the combustion process (air mass flow, lambda, O_2…) and the pollutant emissions (NOx);
4. Design of air path control systems that handle the intake O_2 concentration and the boost pressure;
5. EGR mass flow rate estimation through O_2 and LAMBDA measurements.



Eigenvalue Placement and PID performance over O2 and IMAP.

First name: Giulia **LAST NAME**: VERGERIO

Topic: Balancing energy demand and supply in post carbon cities and societies

Course year: 1st **Tutor(s)**: Stefano Paolo Corgnati, Giulio Mondini

Academic context

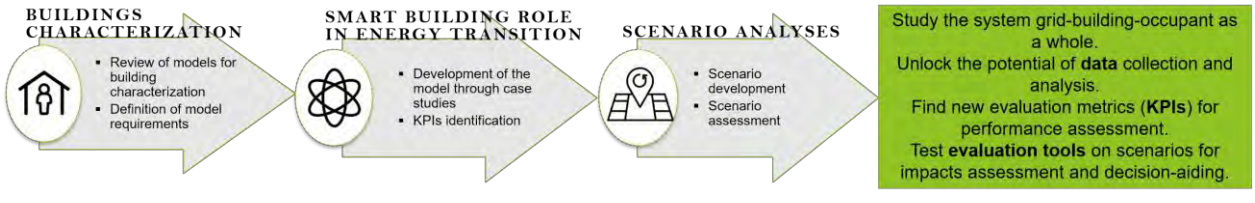
[1] Ghiassi N., Tahmasebi F., Mahdavi A. Harnessing buildings' operational diversity in a computational framework for high-resolution urban energy modelling. Building Simulation (2017) 10: 1005-1021.
[2] IEA (International Energy Agency), EBC (Energy in Buildings and Communities Programme), Statistical Analysis and prediction methods, Annex 53, Volume V, 2013. ISBN: 978-4-9907425-6-0.
[3] Kurnitski J., Hogeling J., Smart readiness indicator (SRI) for buildings not so smart as expected, REHVA Journal, 55(4) (2018) 6-9. ISSN 1327-3729.

External collaborations

- MOBISTYLE project consortium
- ENEA, Italy
- Enel Foundation, Italy

Highlights of the research activity

Cities could be the main actors towards a sustainable future for society and among the urban sectors the existing building stock is particularly relevant. Building energy demand characterization and management is then a key research activity in analyzing buildings role in the energy transition, without disregarding the role buildings have in guaranteeing comfort and welling to the occupants and without forgetting the related socio-economic issues.
The aim of this PhD project is to develop an interdisciplinary methodology for building performance assessment for design/retrofit and management, with a focus on the case study of demand-supply balancing. The first year of PhD has been dedicated to review existing modelling approaches deployed in the research community for building performance characterization, with particular attention to their scale and their application in co-simulation environments. Particular attention has been given to the Reference Building approach, which have been deployed in the "Electrify Italy" project in collaboration with Enel Foundation. However, the new era of digitalization offers new space for building characterization and modelling through data analysis. This topic has been addressed in collaboration with ENEA where the application of statistical analysis to some residential case studies permitted to extract knowledge from monitored data series, in order to describe, know and analyse some of their components, in particular indoor environmental quality parameters and electrical consumptions. Between the diagnostic techniques, some key performance indicators (KPIs) have been identified and computed for the case studies. With respect to KPIs, it should be mentioned that there is a key interest in identifying new multi-domains metrics for the joint assessment in buildings. Further research will be developed in this sense in collaboration with Rehva and within Mobistyle project community. Thanks to Mobistyle, further work will be on data analysis and on Cost-Benefit Analysis application. Indeed, the issue of better characterize and predict the building energy behaviour, in this research, should be the backbone to the broader scope of supporting the decision maker in energy planning for buildings with the support of evaluation tools. Accordingly, the learning process has been addressed also to financial and socio-economic assessment tools exploration (Cost-Benefit Analysis, Multicriteria Analysis, Hybrid methods, decision-aiding tools).



Research outlining

First name: Haosheng **LAST NAME**: WU

Topic: SOLPS-ITER modelling of Asdex Upgrade L-mode

Course year: 3rd **Tutor(s)**: Fabio Subba, Roberto Zanino

Academic context

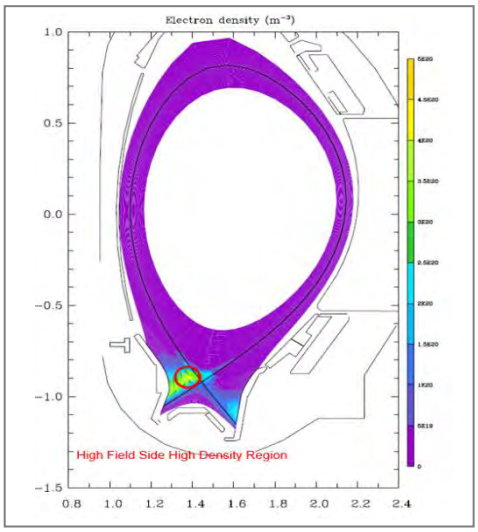
[1] S. Potzel, et al., A new experimental classification of divertor detachment in ASDEX Upgrade, Nuclear Fusion, 54(1): 013001(2013).
[2] L. Aho-Mantila, et al., Assessment of SOLPS5.0 divertor solutions with drifts and currents against L-mode experiments in ASDEX Upgrade and JET, Plasma Physics and Controlled Fusion, 59(3): 035003 (2017).
[3] F. Reimold, et al., The high field side high density region in SOLPS-modeling of nitrogen-seeded H-modes in ASDEX Upgrade, Nuclear Materials and Energy, 12: 193-199 (2017).

External collaborations

- Max Planck Institute for Plasma Physics, Garching
- ITER Organization
- EUROfusion

Highlights of the research activity

My research activity focused on the modelling of the High Field Side High Density (HFSHD) region [1] in AUG L-mode detached plasmas. The SOLPS5.0 code package (B2.5-EIRENE96/99) has been widely used for edge plasma modelling of tokamak devices, e.g. ASDEX Upgrade (AUG) and JET. SOLPS-ITER, which is emerging as the most advanced tool for edge plasma modeling, can be instructed to mimic SOLPS5.0 physics/numerics. The first step of my research activity is to examines the backward-compatibility of SOLPS-ITER with SOLPS5.0 and produces a basic test of the physics/numerics improvements in SOLPS-ITER recommend by SOLPS-ITER developers, taking an ASDEX Upgrade L-mode simulation as an example for future detailed modelling of AUG modelling. A detailed comparison including fluid neutral model and kinetic neutral model shows that SOLPS-ITER match well with SOLPS5.0 under same physics/numerics. Numerical simulation shows that the effect of the recommended physics/numerics on the final solution results in only ~5% differences in outer midplane and target profiles of electron density and temperature. An upstream density scan, covering the full range from attached to detached conditions, also produces closely matching results (~10% differences) between SOLPS-ITER and SOLPS5.0. Thus, we believe that recommended physics/numerics did not introduce unwanted spurious effects and are confident about future modelling results of SOLPS-ITER.



After that, a detailed modelling of AUG discharge shot #27100 and #34821 are preformed, including three detachment state: the onset of detachment state, the fluctuating detachment state and the complete detachment state. The Drifts (ExB and diamagnetic) and currents play an important role in the distribution of plasma and detachment asymmetry. Based on my previous work, the new currents and drifts model in SOLPS-ITER are successfully turn on. The asymmetry of particle flux at inner/outer targets are successfully reproduced in the modelling which is observed in experiments. A pinch velocity are also added in SOL region to mimic the effect of filaments and the formation of the High Field Side High Density region. With drifts and pinch velocity, the HFSHD region observed in experiments are successfully recoverd. A pinch velocity scan (from 10 m/s to 100 m/s) are performed to explore the effect of pinch velocity associated with drifts. In the future, the transport coefficients will be adjusted to match experimental data better.

First name: Alessandro **LAST NAME**: ZANELLI

Topic: Modeling and simulation of innovative electrified diesel propulsion architectures

Course year: 3rd **Tutor(s)**: Federico MILLO

Academic context

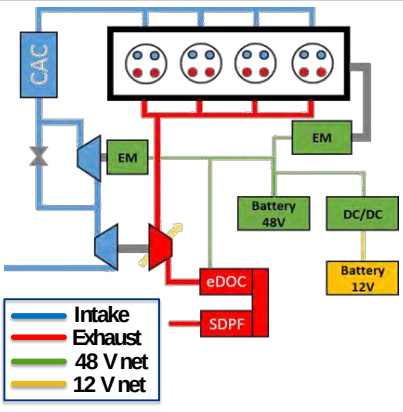
[1] MILLO, F., ROLANDO, L., FUSO, R., MALLAMO, F., Real CO2 emissions benefits and end user's operating costs of a plug-in Hybrid Electric Vehicle, APPLIED ENERGY, vol. 114, pp. 563-571, http://dx.doi.org/10.1016/j.apenergy.2013.09.014
[2] MILLO, F., FERRARO, C.V., ROLANDO, L., Analysis of different control strategies for the simultaneous reduction of CO2 and NOx emissions of a diesel hybrid passenger car. In: INTERNATIONAL JOURNAL OF VEHICLE DESIGN, vol. 58 n. 2/3/4, pp. 427-448, ISSN 0143-3369, http://dx.doi.org/10.1504/IJVD.2012.047393
[3] MILLO, F., BADAMI, M., FERRARO, C.V., ROLANDO, L., Different Hybrid Powertrain Solutions for European Diesel passenger cars, SAE INTERNATIONAL JOURNAL OF ENGINES, vol. 2, pp. 493-504, ISSN 1946-3936, http://dx.doi.org/10.4271/2009-24-0064

External collaborations

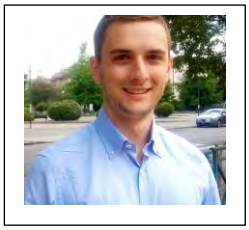
- General Motors Global Propulsion Systems
- Gamma Technologies LLC, www.gtisoft.com
- Roechling Automotive Italia S.r.l., https://www.roechling.com/it/automotive/

Highlights of the research activity

Nowadays OEMs are facing the challenge of producing vehicles that meet more and more challenging fuel economy and emissions targets. Powertrain electrification may represent a viable technology to achieve those targets by using several hybrid architectures. Additionally computer-aided software tools to run simulated test of powertrains plays an important role in the optimization of fuel consumption, performance and reducing pollutant emissions. My research activities started with the development of a comprehensive vehicle and powertrain model with the aim to assess the potentialities of different diesel hybrid architectures. This vehicle features a 48 V electric network in which a 48 V alternator is employed as engine starter and as generator. The low voltage electrification proved to be a cost-effective technology to reduce the fuel consumption and the pollutant emissions. Overall this Mild-Hybrid solution can achieve a reduction of fuel consumption of around 5 % on the Worldwide Harmonized Light Duty Cycle (WLTC). Furthermore, the increased electric power available in a mild hybrid powertrains can be exploited by the introduction of electrified auxiliaries. The introduction of an electric charging device, a so-called electric supercharger (eSC), which is installed in line with the series production turbocharging system, is effective if used as supplementary charge device in improving the vehicle dynamic performance. Concerning the control strategy, a rule based control system has been compared with an Equivalent Consumption Minimization Strategy (ECMS) taking into account the eSC activation power showing little impact on CO_2 emissions. Finally, the introduction of an electric diesel oxidation catalyst (eDOC) may lead to improved light-off time.



Dual voltage 12V + 48V architecture with eSupercharger, Belt Starter Generator and eDOC



First name: Andrea **LAST NAME**: ZAPPATORE

Topic: Modeling innovative HTS conductors for fusion applications

Course year: 2nd **Tutor(s)**: Laura Savoldi (until Oct. 2nd, 2019),
Roberto Zanino (since Oct. 2nd, 2019)

Academic context

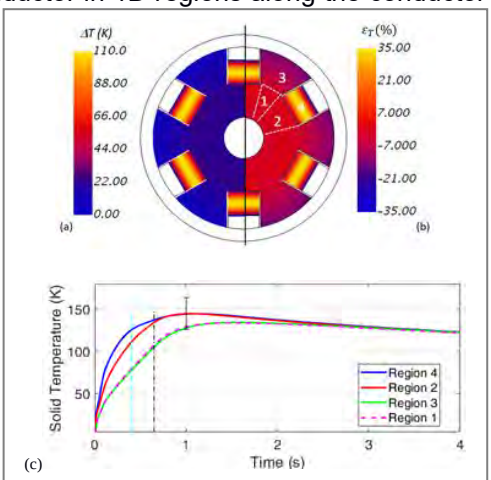
[1] A. Zappatore, W. H. Fietz, R. Heller, L. Savoldi, M. J. Wolf and R. Zanino, A critical assessment of thermal–hydraulic modeling of HTS twisted-stacked-tape cable conductors for fusion applications, Supercond. Sci. Technol. 32 (2019) 084004
[2] A.Zappatore, R. Heller, L. Savoldi, M. J. Wolf and R. Zanino, Analysis of quench in HTS conductors for fusion applications: a novel 1D thermal-hydraulic modeling approach, presented at CHATS-AS workshop, Szczecin, Poland, 9-12 July 2019, available at https://indico.cern.ch/event/776034/contributions/3445074/attachments/1879055/3095326/Zappatore_Andrea_polito_chats2019.pdf
[3] A. Zappatore, A. Augieri, R. Bonifetto, G. Celentano, L. Savoldi, A. Vannozzi and R. Zanino, Modeling quench propagation in the ENEA HTS CICC, presented at MT29 conference, Vancouver, Sep. 22-27 2019, available at https://indico.cern.ch/event/763185/contributions/3415549/attachments/1912610/3187172/Mon-Mo-Or3-06_A_Zappatore_MT26_23sep2019_final_web.pdf

External collaborations

- Karlsruhe Institute of Technology (KIT)
- ENEA

Highlights of the research activity

In the results shown in the previous annual report, detailed 2D analyses of a High Temperature Superconducting (HTS) stack and of an HTS conductor cross-section showed that large temperature differences can arise in the case of fast electro-thermal transients, e.g., quench. These detailed analyses hinted at possible strategy to discretize the cross-section of the conductor in 1D regions along the conductor axis, leading to a 1D multi-regions conductor model [1].
During the second year of the PhD, the code implementing the 1D model has been developed, verified and applied to the simulation of two different conductor designs, namely by KIT [2] and by ENEA [3].
The multi-physics nature of the quench in HTS conductors calls for the modeling of the following features:
1) Evolution of the temperature of the solid components,
2) Evolution of the pressure, speed and temperature of the fluid regions,
3) Evolution of the current of the current-carrying elements.
Furthermore, following the path already shown in [1], a detailed 2D electro-thermal model has been developed also for the ENEA conductor, see Figure. As for the KIT conductor, large temperature differences arise during the quench, see Figure(a). The discretization of the cross-section is shown in Figure(b).
The 1D model of the ENEA conductor has been developed according to that discretization and a quench analysis has been carried out [3]. The evolution of the maximum temperature of selected location in the cross-section confirms that large temperature differences are present during quench, see Figure(c). The model has been also used to parametrically scan some conductor design parameters.



(Top) 2D map of the (a) temperature increase and of the (b) normalized difference between local and average temperature in the ENEA conductor cross-section. (Bottom) Evolution of the hot-spot temperature in different regions in the conductor cross-section.

First name: Tantan **LAST NAME**: ZHANG

Topic: Fluid dynamics of internal combustion engines – diesel injection systems

Course year: 3rd **Tutor(s)**: Alessandro Ferrari

Academic context

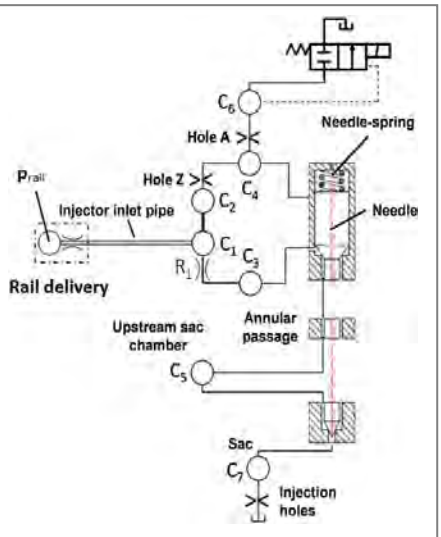
[1] Ferrari A, Zhang T. Influence of the injector setup on digital and continuous injection rate-shaping performance in diesel engine passenger cars. Energy Conversion and Management, In press.
[2] Ferrari A, Zhang T. Benchmark between Bosch and Zeuch method-based flowmeters for the measurement of the fuel injection rate. International Journal of Engine Research, In press.
[3] Ferrari A, Novara C, Paolucci E, Vento O, Violante M, Zhang T. Design and rapid prototyping of a closed-loop control strategy of the injected mass for the reduction of CO2, combustion noise and pollutant emissions in diesel engines. Applied Energy, 232, pp. 358-367.

External collaborations

- Nanyue Fuel Injection Systems Co., Ltd

Highlights of the research activity

The first research activity conducted by me has been to investigate the influences of the injector setup on digital and continuous injection rate-shaping performance in diesel engines [1]. In this activity, A numerical-experimental investigation on a solenoid CR system has been made at the hydraulic test rig to analyze the hydraulic effects of the injection rate -shaping patterns. Parametric analyses have also been performed with a numerical model on the injector mechanical, electrical and hydraulic setups in order to provide design keys for obtaining more efficient rate-shaping strategies, which can allow the potentiality of these techniques to be fully exploited. Finally, two state-of-the-art injectors, one equipped with an integrated Minirail (CRI 2.20) and the other without it (CRI 2.18) have been tested and compared in order to verify and apply the results obtained with the numerical tests. in particular, the connection between the Minirail integrated in the injector with the injection rate phenomena in the short dwell time working zone has been deepened.
The second activity consists of a benchmark between Bosch and Zeuch method-based flowmeters for the measurement of the fuel injection rate [2]. During this study, the theoretical backgrounds of those two types of flowmeters have been analyzed. By applying those two typologies, injection rates under different working conditions have been tested and differences in the results have been found. Afterwards, by applying the Riemann decoupling method, a 1D numerical model of the hydraulic circuit of the flowmeter based on the Bosch method has been built and validated. it has been studied that the cause and the effect relationships between the features of the flowmeter hydraulic circuit and the possible alteration in the measured injected flow-rate pattern.
The last study carried out is related to a rapid prototyping hardware that is able to perform a closed-loop control of the effectively injected quantity for each injection [3]. It was realized by adding pressure sensors onto the rail-to-injector pipe. Two methods have been tested. In the first technique, the fuel mass flow-rate along the rail-to-injector pipe can be calculated, and a correlation between this pipe flow-rate and the injected flow-rate has been utilized to control the injector fueling. The other method is based on the time frequency analysis of the pipe pressure signals, in order to find the corresponding time instants at which the injector needle opens and closes the nozzle. Once those instants have been determined, the injected quantity can be predicted through a correlation between the injected mass and the effective injection time durations. With respect to the first method, the prototyping hardware has been realized and the experimental results are satisfactory for single injections and pilot-main injections.



Scheme of the Common-Rail system hydraulic model