Energy Department
"Galileo Ferraris"
Politecnico di Torino

Energetics PhD

Energetics
Annual Report 2020

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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 2020. 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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- LOGEsoft for LOGEresearch
- Siemens (for STAR CCM+, STAR-CD, ES-ICE)
- Simerics (for SimericsMP+)

CONTENT

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

Topic: Methods for safety and stability analysis of nuclear systems

Course year: 2nd **Tutor(s)**: Sandra Dulla, Nicola Pedroni

Academic context

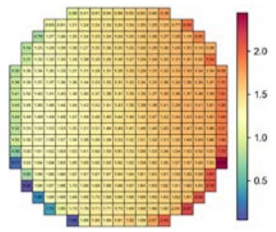
[1] "*A parametrized non-intrusive reduced order model and error analysis for general time-dependent nonlinear partial differential equations and its applications*", D. Xiao, F. Fang, C.C. Pain, I.M. Navon, Comput. Methods Appl. Mech. Engrg., **317**, 868-889, 2017.
[2], "*Assessment of numerical methods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

External collaborations

- INFN Genova (Istituto Nazionale di Fisica Nucleare)

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 purpose of this research topic is to provide an integrated approach, combining the traditional reactor physics numerical methods and some recently developed reduced order models, to reduce the computational burden associated to the numerous simulations typically required for safety assessments of nuclear reactors.
The research activity during the year 2020 has been mainly focused on the development of an in-house Python package to study and develop Parametrised Non-Intrusive (surrogate) Reduced-Order Models (P-NIROMs) for some reactor physics relevant problems [1].



Percentage relative error between P-NIROM and full-order fast neutron flux

The first application of the P-NIROM, presented at the ESREL20-PSAM15 conference, has concerned the study of spatial instabilities that may arise [2, 3] during normal operational phases (e.g. the cold start-up) in a Gen-III+ light water reactor. Due to the challenging nature of the problem, *ad hoc* techniques have been developed to deal with spatially-dependent parameter perturbations, providing promising results as regards the surrogate model ability to reproduce the original model response in a reduced-order simulation framework (see figure). Very satisfactory results have been obtained - with respect to full-order calculations - by applying the reduced model to estimate the reactor power tilts (i.e. the power disequilibrium over the reactor quadrants).
P-NIROM has also been employed for an early-stage parametric study of accidental transients of the ALFRED reactor core using the FRENETIC code. Although the calculations have been carried out in a standalone neutronic mode, the P-NIROM algorithm has proven its effectiveness and accuracy in reproducing the original code behaviour, thus suggesting its possible applicability also in a multi-physics (neutronics and thermal-hydraulics) simulation framework. These results will be presented at the forthcoming M&C 21.
In parallel to these activities, uncertainty quantification studies involving the ALFRED reactor have been started, with the goal of propagating the uncertainties in raw nuclear data to the few-group data employed in full-core calculations. This activity has required three steps: i) extracting the covariance data information from the nuclear data libraries, ii) computing the sensitivity coefficients using the GPT and XGPT routines of the Serpent 2 Monte Carlo code, and iii) combining both the covariances and the sensitivities in order to get first-order estimates of the uncertainty on some few-group data (*e.g.* fission cross section). The final goal of this activity is to propagate the uncertainty in the few-group data to the main multi-physics parameters using the FRENETIC code.
Finally, a part of the research activity has been focused also on more theoretical problems related to the rôle of the different criticality eigenproblem formulations and their connection to the reactor stability.

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

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

Course year: 2nd **Tutor(s)**: Federico Millo

Academic context

[1] Wenig M, Roggendorf K. Development of a Predictive Dual-Fuel Combustion and Prechamber Model for Large Two-Stroke Engines within a Fast 0D / 1D-Simulation Environment. 29th CIMAC World Congr. 2019.
[2] García Valladolid P, Tunestål P, Monsalve-Serrano J, García A, Hyvönen J. Impact of diesel pilot distribution on the ignition process of a dual fuel medium speed marine engine. Energy Convers Manag 2017;149:192–205.
[3] Millo, F., Gianoglio Bernardi, M., and Delneri, D., "Computational Analysis of Internal and External EGR Strategies Combined with Miller Cycle Concept for a Two Stage Turbocharged Medium Speed Marine Diesel Engine," SAE Int. J. Engines 4(1):1319-1330, 2011.

External collaborations

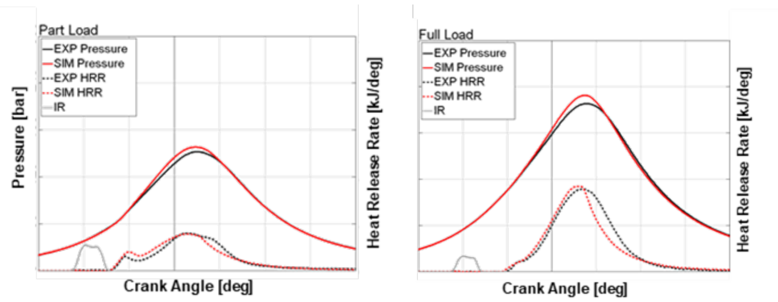
- Wärtsilä
- Gamma Technologies LLC
- Powertech Engineering

Highlights of the research activity

The research activity, sponsored by Wartsila, concerns the development and the assessment of a predictive combustion model for large dual fuel engines, which are fueled by natural gas and are ignited by a small amount of diesel fuel injected in the cylinder. The dual fuel combustion model recently released by Gamma Technologies in the commercially available software GT-SUITE was considered for this research activity.

During this second year my activity focused on the investigation of the chemistry involved in the combustion process. One point crucial for my research activity was to capture the interaction between the two fuels and to develop a methodology to consider this interaction in a multizone combustion model. More in detail, the methane was shown to have a significant inhibiting effect on pilot diesel fuel reactivity. This finding, in line with many studies available in the literature, was addressed by developing a suitable ignition delay model in which the methane inhibiting effect is considered. The ignition delay model was based and correlated against 0D-CFD detailed chemistry results and it was integrated in the multizone combustion model, leading to accurate prediction of the ignition delay under several engine operating conditions. Subsequently, to improve the predictive capabilities of the combustion model, a refinement of the laminar flame model was carried out. A power-law correlation was developed for the evaluation of the gas laminar flame speed under relevant engine operating conditions. This function was correlated against 1D-CFD detailed chemistry calculations and integrated in the dual fuel combustion model. A comparison between experimental and predicted results in terms of pressure and heat release rate is reported in Figure 1.

Another important point highlighted though a detailed experimental data analysis and confirmed also by means of 3D-CFD results was the effect of the spray characteristics on the gas flame propagation. To face this complex interaction, I am currently working in close collaboration with Gamma Technologies developers on the turbulence flame speed model to improve the predictive capabilities of the combustion model.



(a) (b)

Experimental vs predicted in-cylinder pressure in solid lines and heat release rate in dashed lines: (a) Part Load operating condition; (b) Full Load operating condition

First name: Ciro **LAST NAME**: ALBERGHI

Topic: Analysis of MHD and tritium transport in liquid breeders for fusion applications

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

Academic context

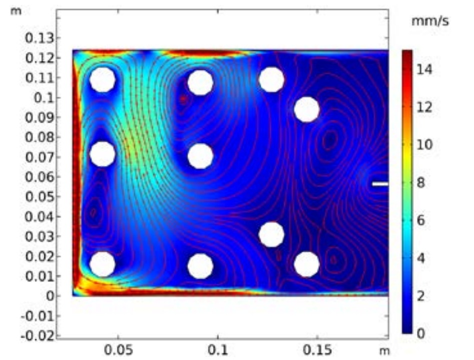
[1] Alberghi, C., Candido, L., Testoni, R., Utili, M., Zucchetti, M., "*Magneto-convective effect on tritium transport at breeder unit level for the WCLL breeding blanket of DEMO*", Fusion Engineering and Design, 160(2020).
[2] Candido, L., Testoni, R., Utili, M., Zucchetti, M., "*Tritium transport model at breeder unit level for WCLL breeding blanket*", Fusion Engineering and Design, 146(2019).
[3] Testoni, R., Candido, L., Utili, M., Zucchetti, M., "*Tritium transport model at breeder unit level for HCLL breeding blanket*", Fusion Engineering and Design, 146(2019).

External collaborations

- ENEA
- EUROfusion
- Fusion for Energy

Highlights of the research activity

During the first year of PhD, a new MHD and tritium transport code for WCLL breeding blanket was developed. Lithium-lead flow in a 3D portion of the WCLL 2018 was simulated, considering a magnetic field of 4 T and buoyancy forces. The velocity field was used as input for the tritium transport calculations. The temperature field and velocity profile of lithium-lead (shown in Fig. 1) and tritium inventories and losses, fundamental quantities for what concerns the design and safety of future fusion systems, were obtained. In addition, a sensitivity analysis on Sievert constant highlighted the need of new values of the solubility of hydrogen isotopes in lithium-lead.



Magnetoconvective velocity profile of the LiPb between the first wall and the baffle of the WCLL BB under a magnetic field of 4 T.

To support the MHD modelling activities, the verification and validation of the developed code was performed. Multiple benchmark problems, characterized by different MHD flows, were solved, and the results were compared to known analytical and numerical solutions or experimental results. They concern steady state, fully developed flows in rectangular ducts, flow in a spatially-varying transverse magnetic field, and two turbulent problems, quasi-two-dimensional MHD turbulent flow and 3D turbulent MHD flow entering a magnetic obstacle. Moreover, to tackle the severe nonuniform temperature distribution in the breeding blanket, two buoyancy-driven flows were investigated. The computed results showed good agreement with the reference solutions, for all the addressed problems, suggesting that the developed code can be used to study liquid metal MHD problems under the flow regimes typical of fusion power reactors.
Regarding the experimental activities, the upgrade of Hyper-Quarch (Hydrogen Permeation Quartz Chamber) facility at ENEA C. R. Brasimone was designed. The system construction started in October 2020 and ended in December 2020. The facility will be used to calculate Sievert constant of hydrogen isotopes in lithium-lead, in order to obtain a new and more reliable value, and to characterize hydrogen permeation sensors.

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

Topic: Heat and mass transfer in porous and structured materials for novel devices: towards the water and energy nexus

Course year: 2nd **Tutors**: Pietro Asinari, Eliodoro Chiavazzo, Alberto Tiraferri

Academic context

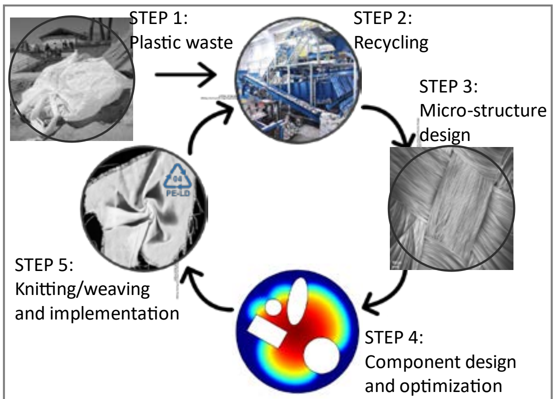
[1] Vaartstra, G., Zhang, L., Lu, Z., Díaz-Marín, C. D., Grossman, J. C., & Wang, E. N. (2020). Capillary-fed, thin film evaporation devices. Journal of Applied Physics, 128(13), 130901.
[2] Boriskina, S. V., Raza, A., Zhang, T., Wang, P., Zhou, L., & Zhu, J. (2019). Nanomaterials for the water-energy nexus. *Mrs Bulletin*, *44*(1), 59.
[3] Alberghini, M., Morciano, M., Fasano, M., Bertiglia, F., Fernicola, V., Asinari, P., & Chiavazzo, E. (2020). Multistage and passive cooling process driven by salinity difference. Science advances, 6(11), eaax5015.

External collaborations

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

Highlights of the research activity

Passive devices relying on capillary wicking and evaporation offer a robust, cheap, off-grid and sustainable alternative to a wide variety of applications, ranging from personal thermal management to passive devices for water treatment, from filtration to sustainable cooling. The research activity focused on modelling the interplay between the structural properties of porous materials and the different heat and mass transfer mechanisms involved, both at the micro- and macroscale: their full comprehension is crucial to correctly design and engineer the thermal performances of novel materials for several applications in the energy engineering field.



Closed-loop life cycle of polyethylene-based materials for passive devices relying on capillary action and evaporation.

In the framework of personal thermal management applications, the micro-structural parameters characterizing a plain-woven polyethylene textile, evaluated trough a dedicated experimental investigation, were used to develop a detailed analytical model aimed to understand and optimize the transport of water within polymeric fabrics. The model was then validated against experimental data, used to extrapolate the combination of parameters that would maximize the capillary properties of a textile and as an assessment tool to evaluate the surface free energy of hydrophilic impermeable fibers.
Then, the macroscopic thermal performances of hydrophilic porous media where investigated by a novel comprehensive model coupling capillary suction, evaporation and radiative heat transfer: each phenomenon was singularly modelled and validated against dedicated experimental data. With the objective of outlining some guidelines in the design process of novel materials for personal thermal management, the comprehensive model was used to determine the effects of different ambient conditions on the shares of radiative and evaporative heat fluxes, aiming to maximize their performance in a given working condition. Furthermore, the model was used to perform a sensitivity analysis to assess the effects of the wicking properties on the optimal geometry of a capillary-fed component for water treatment, with the intention to provide an example of model-assisted design of a key-part of such devices. The obtained results showed a deep interconnection between the different heat and mass transfer mechanisms, the porous structure and the external working conditions. Thus, modelling their non-linear behavior plays a crucial role in determining which physical properties and geometrical feature should be optimized to maximize the performance of porous materials for the energy sector.

First name: Elena **LAST NAME**: BADINO

Topic: Optimization of building façade features to enhance environmental quality at the urban microscale

Course year: 1st **Tutor(s)**: Arianna Astolfi, Valentina Serra, Louena Shtrepi

Academic context

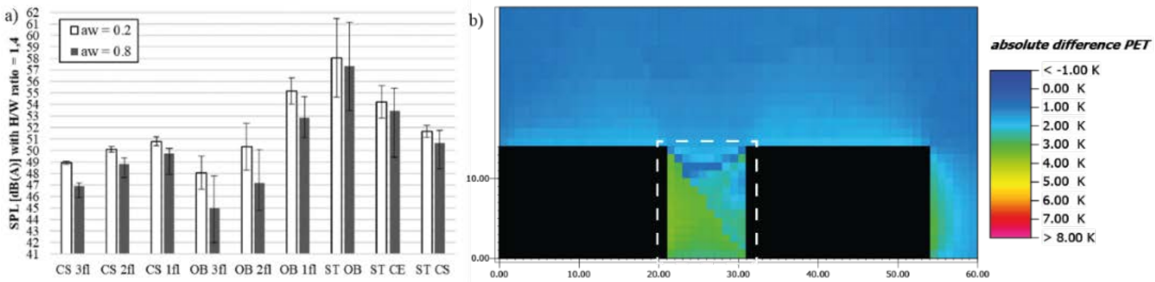
[1] W. Yang, J.Y. Jeon, Design strategies and elements of building envelope for urban acoustic environment, Build. Environ. 182 (2020)
[2] E. Badino, R. Manca, L. Shtrepi, C. Calleri, A. Astolfi, Effect of façade shape and acoustic cladding on reduction of leisure noise levels in a street canyon, Build. Environ. 157 (2019) 242–256.
[3] E. Naboni, A. Milella, R. Vadalà, F. Fiorito, On the localised climate change mitigation potential of building facades, Energy Build. 224 (2020).

External collaborations

- University of Naples Federico II, Naples, Italy
- CEMEX Research Group AG, Brügg, Switzerland
- University of Washington, Seattle, WA, USA

Highlights of the research activity

The research endorses the conception of buildings façades as interfaces between indoor and outdoor environments, able to benefit both conditions. In particular, it investigates the potential contribution of façade design to outdoor thermal and acoustic comfort conditions in the urban environment. The research aims to identify a methodological approach to evaluate the effect of different geometric features and material properties of façades (e.g. albedo, emissivity, sound absorption and sound scattering coefficients) in order to enhance outdoor thermal and acoustic comfort perceived by pedestrians at the street level and by dwellers in balconies and terraces. Several tools able to predict sound propagation and microclimatic variables in urban environments are available, offering different degrees of accuracy, computational time and interoperability with modeling environments. However, their capabilities and limitations are often unclear to potential users, possibly leading to incorrect interpretations of the results. In past studies, both wave-based and geometric acoustic approaches have been adopted to investigate sound propagation in cities. However, there is the need to further assess their accuracy in complex urban environments with respect to measured data and to identify tools suitable for early design phases. Moreover, a literature review has been conducted to compare the calculation approaches of common simulation tools to estimate the mean radiant temperature, that is the key parameter influencing outdoor thermal comfort during summertime. The simulation results will be compared to measured data to assess their accuracy. A preliminary study on the effect of façade cladding material properties on outdoor thermal and acoustic comfort in a street canyon has been conducted using ENVI-met and Pachyderm. The study highlights the often-overlooked impacts of cladding material choices: indeed, different radiative and sound absorbing properties of claddings materials result in significant changes in the sound pressure level (SPL) and in the Physiological Equivalent Temperature (PET) perceived by pedestrians and dwellers.



Variation in the mean A-weighted SPL at the different building floors over the façades (CS and OP) and at the street level (ST) due to the application of sound absorbing claddings to the side buildings of the street; b) color map of the differences in PET in the street section, due to the application of high-albedo cladding materials.

First name: Stefano **LAST NAME**: BAZZOLO

Topic: Sistemi innovativi per il trasporto urbano con trazione a fune: progettazione e consumi energetici
Cable driven innovative systems for urban transport: engineering, design and energy consumption

Course year: 2nd **Tutor(s)**: Bruno Dalla Chiara

Academic context

[1]. Navone M., Dalla Chiara B., Blengini S., Vair E., Cable driven Automated People Movers for urban applications: modelling the roller for investigating energy consumption, Ingegneria Ferroviaria, vol. LXX, N 9, pp 631-663, Sept.2017
[2]. Affatato M., Blengini S., Dalla Chiara B., Vair E., Automated People Mover with rope traction: engineering and modelling an innovative hybrid solution to optimise energy use, Ingegneria Ferroviaria, vol. LXX, ISSN: N. 11, pp. 901-923, Nov. 2015
[3]. UNI, "Linee guida per la progettazione dei sistemi di trasporto persone ad automazione integrale (APM) con trazione a fune", 2018

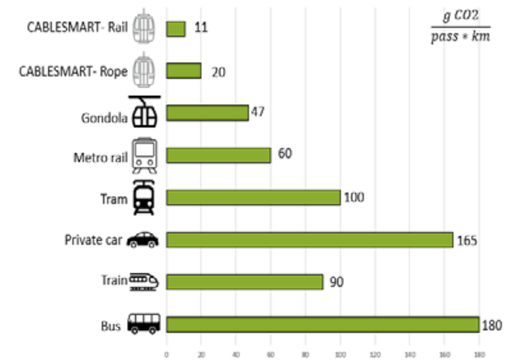
External collaborations

- Dimensione Ingenierie s.r.l.

Highlights of the research activity

Main goal of the research activities during the three-years PhD program is to analyze the urban transport systems derived by cable car system, with particular reference to hybrid systems, where propulsion can be given to the vehicle through two different ways: 1) the clamping or gripping to a cable, similarly to a traditional cable car; or 2) through motorized wheels mounted on the vehicle, similarly to a monorail or to a small light rail.

In the first year, a comparative analysis on energy consumption between the hybrid cable car-motorized wheels and other public transport systems was carried on. This analysis shows that the above-mentioned hybrid system has better performances in terms of energetic impact [kWh/(pass*km)] and emissions [gCO_2/(pass*km)]. The analysis was made about the line segment on motorized wheels, as scientific literature already contained studies made about cable car sectors. Energy simulation was carried on by considering different traffic scenarios and different cities (London, Dubai City, Torino and New Delhi), and it was shown that the request of energy to the net can be further reduced until 50% in Torino and until 70% in cities with particularly advantageous conditions weather by installing photovoltaic plant and an energy storage system through batteries. The above descripted analysis was published in the paper “Energy load analysis of a fully automated hybrid cable-driven public transport system: simulation with a photovoltaic system and storage” (Bazzolo S., Dalla Chiara B., Blengini S.) published in December 2019 issue of “Ingegneria Ferroviaria” (Scopus). Moreover, the research activity was focused in the first year in the pre-design of several installations of cable car-motorized wheel transport systems, with particular reference to the integration with the system in the urban context (strength of motorized wheel segments) and to the easy passing of natural and anthropic obstacles (strength of cable car segments). Pre-designs were carried for Genova, Sorrento and Maiori contexts, while more in-depth engineering and design activities are foreseen in the next year.



Comparation among hybrid cable car-motorized wheels system and other transport system in terms of emissions [gCO2(/pass·km)]

First name: Francesco Maria **LAST NAME**: BELLUSSI

Topic: Heat and mass transfer phenomena at the soft matter interface for energy devices

Course year: 1st **Tutor(s)**: Pietro Asinari, Matteo Fasano

Academic context

[1] Nejad, Shahin Mohammad, et al. "Nanoscale thermal properties of carbon nanotubes/epoxy composites by atomistic simulations." *International Journal of Thermal Sciences* 159: 106588.
[2] Wang, Dehui, et al. "Design of robust superhydrophobic surfaces." *Nature* 582.7810 (2020): 55-59.
[3] Leroy, Frédéric, and Florian Müller-Plathe. "Dry-surface simulation method for the determination of the work of adhesion of solid–liquid interfaces." *Langmuir* 31.30 (2015): 8335-8345.

External collaborations

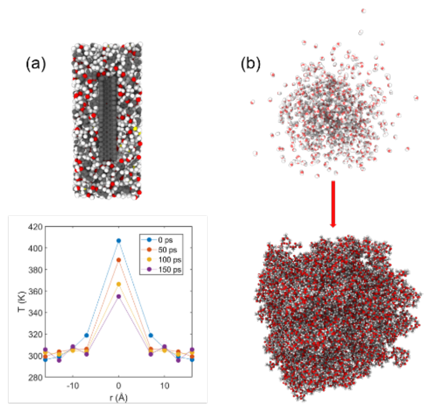
- Roma Tre University

Highlights of the research activity

During the first year of the PhD I focused the attention of the research activity on the atomistic modeling of nanoscale heat and mass transfer phenomena at the soft matter interfaces. In particular, I have been involved in two main study cases: 1) the evaluation of the effective thermal conductivity of epoxy resin reinforced with carbon nanotubes; 2) the evaluation of the wettability properties of polymeric coatings.

As regards the study case 1, the importance of studying carbon based epoxy nanocomposites for energy applications is due to their theoretical high thermal transfer provided by the carbon filler in addition to their lightweight and structural strength. However, an optimal design which involves different scales is required for their development, since the properties of the filler-polymer interface play a significant role on the effective thermal transport. Furthermore, since these characteristics take place in a space region of few angstrom, experimental campaigns and continuum simulations are unable to characterize such phenomena. Instead, molecular dynamics (MD) simulations can provide a representative description of the thermal conduction dependence on the interfacial characteristics and how different interfaces can regulate the thermal transport across nanocomposites. In detail, for the development of this work I have applied different MD protocols (transient approach and reverse non equilibrium MD) for the evaluation of the interface thermal resistance and the effective thermal conductivity, as well as the effect of different geometry setups and different numerical methods for the application of the thermostats to the system.

As far as the study case 2 is concerned, the interest in surface properties of polymeric coatings is justified by their low surface free energy, making them good candidates for the development of energy devices due to their characteristic of low wettability. Also in this case MD simulations represent good tools for the characterization of surface and interface features, helping the rational design of materials. More in detail, for the development of this work I applied the free energy perturbation approach for the evaluation of the work of adhesion between polylactic-glycol acid (PLGA) or perfluorodecanoic acid (PFDA) and several solvents, such as water, formamide and diiodomethane. Then, applying the Young-Dupré equation I evaluated the contact angle of the solvents on the PLGA surface.



(a) Molecular model of CNT-Epoxy nanocomposite with temperature profile at the interface [1]. (b) Molecular setup for the polymer wettability simulation; details of water molecules on PLGA surface.

First name: Matteo **LAST NAME**: BILARDO

Topic: From Zero Energy to Zero Power Buildings

Course year: 1st **Tutor(s)**: Enrico Fabrizio

Academic context

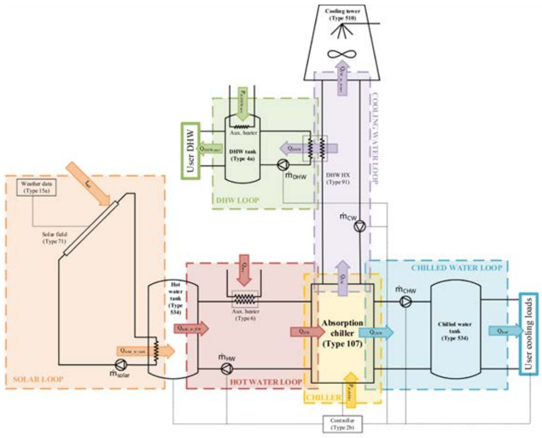
[1] Bilardo, M., Ferrara, M., & Fabrizio, E. (2020). Performance assessment and optimization of a solar cooling system to satisfy renewable energy ratio (RER) requirements in multi-family buildings. Renewable Energy, 155, 990–1008.
[2] Bilardo, M., Sandrone, F., Zanzottera, G., Micono, C., & Fabrizio, E. (2020). A numerical model for the energy assessment of a fifth-generation district heating and cooling (5GDHC) network. In SDEWES (Ed.), Proceedings of the 15th SDEWES Conference (pp. 1–15), Cologne.
[3] D'Agostino, D., Mazzarella, L. What is a Nearly zero energy building? Overview, implementation and comparison of definitions. J. Build. Eng. 2019, 21, 200–212, doi:10.1016/J.JOBE.2018.10.019.

External collaborations

- SmartData@Polito, Department of Mathematical Sciences (DISMA), Politecnico di Torino
- COESA srl, Corso Francia 30, Torino, Italy
- Department of Agricultural, Forest and Food Sciences (DISAFA), Università degli Studi di Torino

Highlights of the research activity

The aim of the research activity is to study energy utilization and generation within the built environment by focusing on shorter time intervals. In this research scenario, we want to explore the future transition from the most well-known and globally recognized nearly Zero Energy Building (nZEB) to a so-called nearly Zero Power Building (nZPB). The detailed analysis on short time intervals, ideally tending to zero, is therefore necessary to address this research topic.
To better engage this topic, the research activity carried out so far has concentrated on different levels of detail. Starting from the single component, an experimental activity on an Integral Collector Storage (ICS) prototype allowed to advance important conclusions on the innovative application of future devices for the production of domestic hot water in buildings. Following the same principle, a further research task focused on a complete HVAC system based on an absorption chiller powered by a solar source. Also in this case, the research aimed to evaluate the energy impact of an innovative system to satisfy the summer cooling load of a multi-family residential building. In the context of nearly Zero Power Buildings, the analysis was conducted following a dynamic approach using a direct numerical model. The latest developments of this work have also found a collaboration with the SmartData @ Polito research group with the aim of exploring possible artificial intelligence algorithms applied on building physics problems.
Having approached research issues related to the energy efficiency of buildings both on a small scale (single component for DHW production) and on a medium scale (entire HVAC generation system), the research path is developing on a scale even larger. The latest research activities have in fact placed groups of buildings or entire districts at the centre of attention, exploring the benefit of new generation district heating and cooling networks. The development of this new study aims to extend the concept of nearly zero energy/power buildings no longer in the perspective of the single building, but rather within a larger scenario where the energy exchange and interaction between more facilities becomes essential. This activity, carried out in collaboration with an energy saving company based in Turin, has already given the first numerical results.



Solar cooling system modelled in TRNSYS®

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

Topic: Adaptive Control Strategies for improving energy flexibility in buildings

Course year: 2nd **Tutor(s)**: Alfonso Capozzoli

Academic context

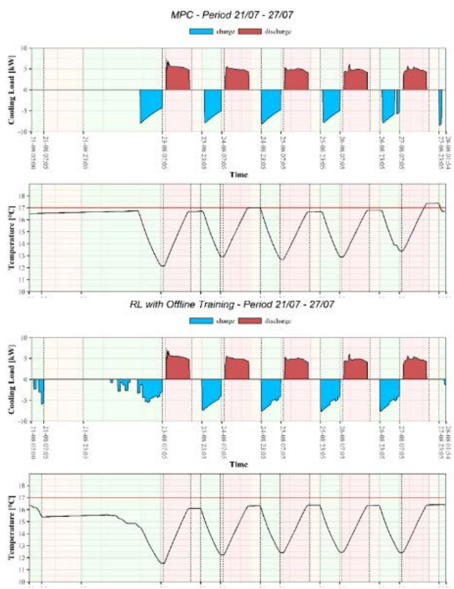
[1] Vàzquez-Canteli J., Nagy Z. Reinforcement learning for demand response: A review of algorithms and modeling techniques. Elsevier, Applied Energy (2019) 235:1072-1089 https://doi.org/10.1016/j.apenergy.2018.11.002
[2] Brandi S, Piscitelli MS, Martellacci M, Capozzoli A, Deep reinforcement learning to optimise indoor temperature control and heating energy consumption in buildings, Energy and Buildings (2020) 224 https://doi.org/10.1016/j.enbuild.2020.110225.
[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

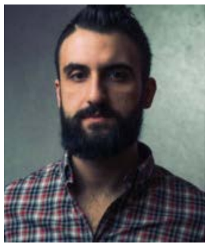
- Enerbrain s.r.l.
- University of Texas (Austin)
- EMPA

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.
An integrated simulation environment combining EnergyPlus and Python, was developed. 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.



The research direction explored during 2020 involves the employment of the simulation environment described above to compare the model-free approach of RL with a model-based approach of Model Predictive Control (MPC). In this work, a simple system which includes a cold-storage serving two office rooms was taken into consideration. The objective of the controllers is to optimize the charging and discharging of the storage in order to minimize the total electricity cost of the system. The storage can be charged through a chiller unit which also serves the building in the case the storage is not available. The first results depicted in the figure shown how both DRL and MPC controllers achieved similar performances improving the baseline control policy of a Rule-Based Controller (RBC) adapting perfectly to price schedules. The two advanced controllers were tested with both perfect and imperfect predictions of external disturbances in order to assess their ability to optimally manage the system under varying conditions.



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

Topic: Lithium-lead and Tritium Technologies

Course year: 2nd **Tutor(s)**:Massimo Zucchetti, Raffaella Testoni

Academic context

[1] M. Utili, et al., "Tritium Extraction from HCLL/WCLL/DCLL PbLi BBs of DEMO and HCLL TBS of ITER," IEEE Transactions of Plasma Science, vol. 47, no. 2, pp. 1464-1471, 2019.
[2] L. Candido, et al., "Characterization of Pb-15.7Li Hydrogen Isotopes Permeation Sensors and Upgrade of HyPer-QuarCh Experimental Device," IEEE Transactions on Plasma Science, vol. 48, no. 6, pp. 1505-1511, 2020.
[3] I. Ricapito et al., "Tritium technologies and transport modelling: main outcomes from the European TBM Project," Fusion Engineering and Design, vol. 136, no. January, pp. 128–134, 2018

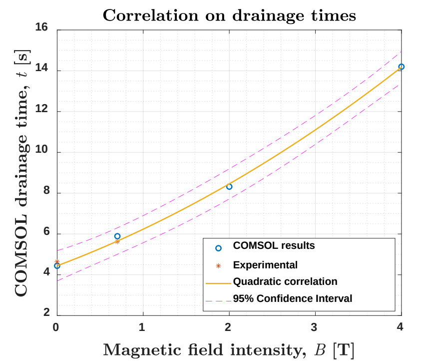
External collaborations

- ENEA
- CEA
- Fusion 4 Energy

Highlights of the research activity

The second year of activities was focused on the following items:

- Prosecution of the activity related to the development of a tritium permeation sensor for the Gen-IV ASTRID sodium fast reactor. In particular, the engineering design was assessed in order to be installed in CEA Superfennec sodium loop.
- Study of the fast drainage of the pumping channel of IELLLO loop installed at ENEA Brasimone research center in order to quantify the draining time and time delay induced by the presence of an external magnetic field. The research included both experimental and modelling activities and was awarded with 3rd place at TOFE international conference.
- Development, assembly, and commissioning tests of Hyper-Quarch II (Hydrogen Permeation Quartz Chamber) experimental device devoted to the qualification of hydrogen permeation sensors and to the measurement of Sieverts' constant of hydrogen isotopes (protium nd deuterium) solubilized in liquid lithium-lead alloy.
- Development of a novel approach to the study of the magneto-hydro-dynamics (MHD) effect to the tritium transport in the WCLL breeding blanket of DEMO. The integrated modelling was based on a multi-physics approach able to combinate neutronics, MHD and transport. The 3D model was able to describe the volumetric power deposited to the breeder unit, the internal rate of tritium generation, the MHD velocity, temperature and electric potential profiles, the tritium retention and permeation into the different materials. This study is fundamental from a point of view of design of the WCLL and safety.



Correlation between draining time and external magnetic field for the drainage of pumping channel.

- Experimental campaign on TRIEX-II facility as a prosecution of the activities started in 2018. In particular, the facility, used to test and qualify tritium extraction technologies such as the gas/liquid contactor (GLC) and the permeator against vacuum (PAV) concepts, was used to test the GLC technology for DEMO relevant conditions.

First name: Martina **LAST NAME**: CAPONE

Topic: District heating network modelling towards next generation energy infrastructures

Course year: 1st **Tutor(s)**: Vittorio Verda, Elisa Guelpa

Academic context

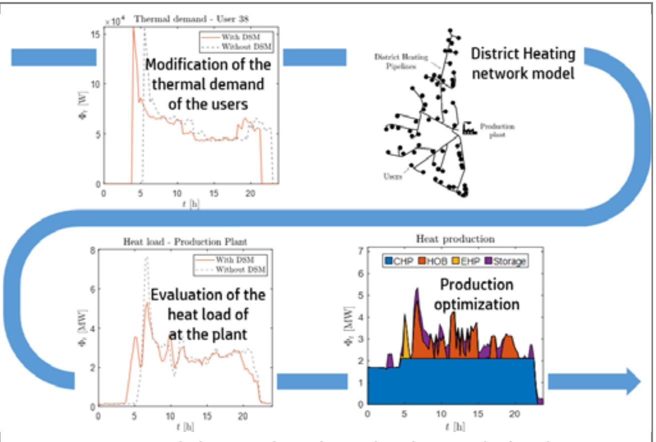
[1] H. Lund et al., “4th Generation District Heating (4GDH) - Integrating smart thermal grids into future sustainable energy systems”, Energy 68 (2014) 1-11.
[2] P. Mancarella, “MES (multi-energy systems): An overview of concepts and evaluation models”, Energy 65, 1–17 (2014).
[3] M. Capone, E. Guelpa, V. Verda, “Optimal operation of district heating networks through demand response”, International Journal of Thermodynamics 22, 25-43 (2019).

External collaborations

- Iren S.p.A.
- Yanmar R&D Europe S.r.L.

Highlights of the research activity

During the past few years, District Heating (DH) technology is experiencing a gradual transition towards a totally renovated generation of systems (4th generation district heating [1]), which aims at reaching a future non-fossil society based on renewable energy sources like solar, waste heat and geothermal energy.
In this framework, it is essential to use suitable numerical models to simulate and optimize the operation of existing and future district heating networks. Hence, part of the research activity of my first year of PhD was devoted to the refinement of a physical model, which was identified after an extensive literature review. Different adjustments were introduced to improve the accuracy of the results; an example is the introduction of the thermal capacity of the pipe in the solution of the energy conservation equation. Moreover, the model was integrated with a previously-developed grey-box building model in order to preserve the quality of the solution even when the users’ data set is modified. To test the model, some applications to the Turin case study were carried out using real data made available by IREN. Afterwards, by analyzing the temperature dynamics, special attention was paid to the influence of the water cooling during the night. This led to the idea of a new management strategy to reduce the morning thermal peak, which was detailed in a patent application.
A crucial application of the model was related with the integration of DH with the electric grid, in a “smart energy system” perspective. In this context, the possible electricity excess can be adopted for heating purposes by means of heat pumps. The transient thermal model was used to evaluate the potential energy savings. Also, the influence of the positioning of a heat pump within an existing DH network was assessed by means of a steady-state simulation associated to exergy analysis.
Finally, a further step in this research area was concerned with the simultaneous optimization of production and demand in a multi-energy context. A system including production/conversion plants, storages, distribution networks and users with flexible heating demand (i.e. subjected to heat demand side-management) and fixed electricity and cooling loads was optimized to find the optimal operation evolution of the technologies, the best modification to the thermal request of each user and the best storage size. This was done through a bi-level optimization structure. The developed model allows estimating the optimum from economic, environmental and multi-objective perspective.



Integrated demand and production optimization

First name: Alessandro **LAST NAME**: COLANGELO

Topic: Thermal Energy Storage Technologies

Course year: 1st **Tutor(s)**: Vittorio Verda, Andrea Lanzini

Academic context

[1] Y. Dutil et al., A review on phase-change materials: Mathematical modeling and simulations, Renewable and Sustainable Energy Reviews (2011) 112-130.

[2] A. Sciacovelli et al., Maximization of performance of a PCM latent heat storage system with innovative fins, Applied Energy (2015) 707-715.

[3] F. Colella et al., Numerical analysis of a medium scale latent energy storage unit for district heating systems, Energy (2012) 397-406.

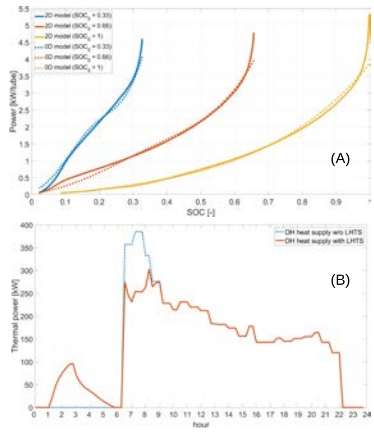
External collaborations

- RE-COGNITION consortium (https://re-cognition-project.eu/)
- i-TES SRL (https://www.i-tes.eu/?lang=it)

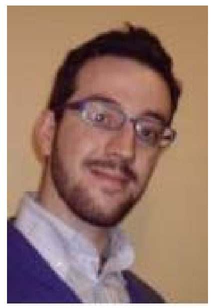
Highlights of the research activity

The research activity is developed within the framework of the European project RE-COGNITION, which aims at an optimal integration of multiple storage and renewable energy systems at the building scale through modern information and IoT technologies. In particular, this research activity is focused on a shell-and-tube Latent Heat Thermal Storage (LHTS) filled with an appropriate Phase Change Material (PCM). The main objective is to elaborate models of different complexity able to simulate and examine various LHTS operating conditions in order to optimally coordinate its operations within a multi-energy system. These models will be tested and calibrated in the experimental facility available at the Energy Center on two different storage prototypes, which are currently being manufactured.

After a comprehensive literature review, two main research gaps were identified. On the one hand, very few articles propose models for multi-tube LHTS systems; the analyses generally concern the optimization of fins design in single tube prototypes. On the other hand, a limited number of studies focus on the operational phase of LHTSs (such as subsequent charge and discharge cycles, partial charge and discharge, etc.). Therefore, models for the simulation of various operating conditions and experimental tests in a relevant environment are essential in order to increase the maturity of this technology. A model for the simulation of LHTS operating conditions should be characterized by a tradeoff between quick results and an accurate physical description. Considering the physical complexity of the phase change in PCMs and the heat transfer in shell-and-tube configurations, the subsequent model simplification approach was followed. First, a 2D detailed numerical model was produced with Ansys Fluent. Then, its results were condensed in a simpler and compact model (0D) suitable for quick simulations. Thanks to symmetry, the 2D model represents an elementary unit of a multi-tube LHTS system with longitudinal fins. A mathematical correlation was then established between the simulated LHTS thermal power (resulting from the 2D model) and its state of charge (i.e. the ratio between the actual energy contained in the storage at a specific time instant and its maximum value). This procedure was repeated for both the charging and discharging phases. As a result, the LHTS thermal power characteristic curves were obtained as a function of only two parameters: the state of charge at the beginning of each new charge/discharge phase and the current state of charge at a specific time instant. The 0D model was then applied to a case study regarding the reduction of the District Heating (DH) peak demand.



(A): LHTS power characteristic curve;
(B): application to DH peak reduction



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

Topic: Advanced modelling of lubricated gaps in positive displacement machines

Course year: 2nd **Tutor**: 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] Uwe WIECZOREK (2000) - "Simulation of the gap flow in the sealing of bearing gaps of axial piston machines", Proc. of 1st FPNI-PhD Symp. Hamburg 2000.
[3] Divya Thiagarajan & Andrea Vacca (2017) - "Mixed Lubrication Effects in the Lateral Lubricating Interfaces of External Gear Machines: Modelling and Experimental Validation", Energies **10**(1), 111.

External collaborations

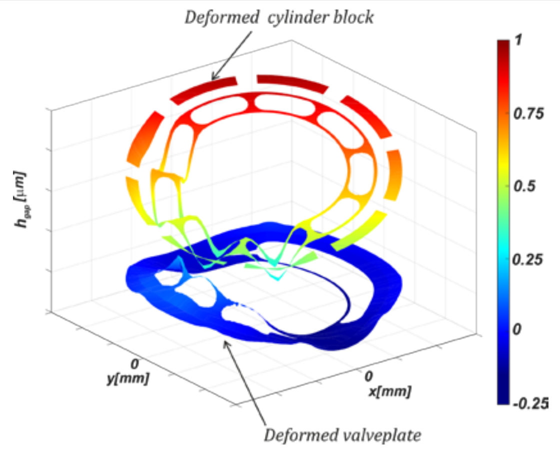
- Casappa S.p.A.

Highlights of the research activity

The study of lubricated interfaces in fluid power components involves multidisciplinary problems, from fluid mechanics to structural analysis, and mathematical numerical methods.
The second year of the PhD was focused on improving the existing tribological model of the cylinder block - valve plate interface in axial piston pumps. In particular, several enhancements have been implemented in the actual model to allow the simulation of:

- mixed / boundary lubrication and load capacity;
- elastic deformation of both surfaces constituting such an interface.

Concerning the mixed lubrication condition, a simplified and original method was introduced to evaluate the effective contact area on the i-th elementary cell adopting a statistical approach. The basic idea is to estimate this area as the overlapping surface between two skew probability density functions based on the root mean square roughness (Rq) and the skewness roughness (Rsk) measured on the components. This new feature allows the designer to predict the likely wear regions on the valve plate and to contrast different geometries with the aim of reducing the wear.



Deformed surfaces of valve plate and cylinder block due to the pressure field.

Considering the elastic deformation of both bodies (valve plate and cylinder block), the methodology adopted was the offline evaluation of the influence matrices to be supplied to the model at each time-step. Being the valve plate a fixed component, the generation of its matrix is a quite straightforward process, conversely the cylinder block rotates, and since the pressure inside the displacement chambers varies over the time, as many influence matrices as time-steps of the simulation are required.
Fig.1 shows an example of deformed valve plate and cylinder block surfaces during the simulation.
For the evaluation of the leakage flow rate of each displacement chamber through the deformed surfaces, a new vectorial leakage approach was implemented.
These new steps lead to an improvement of the dynamic behaviour of the model and to a better convergence, especially in mixed friction condition.

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: 3rd **Tutor(s)**:Enrico Fabrizio, Salvador Calvet Sanz

Academic context

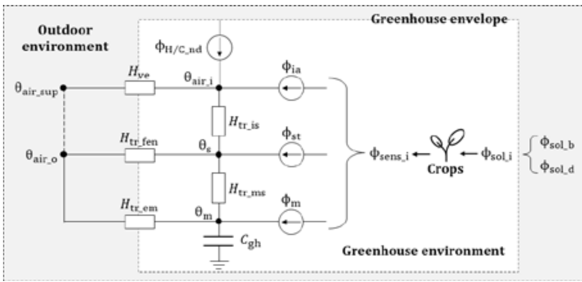
[1] FAO, Energy-Smart Food at FAO: an Overview, FAO, Rome, Italy, 2012
[2] M.A. Hellickson, J.N. Walker, Ventilation of Agricultural Structures, ASAE Monograph Number 6, American Society of Agricultural Engineers, St. Joseph, Michigan, 1983
[3] ASHRAE, Environmental Control for Animals and Plants, in: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

External collaborations

- Institute for Animal Science and Technology, Universitat Politècnica de València (UPV), Valéncia, Spain
- LivAGE COST Action (CA16106) – Ammonia and Greenhouse Gases Emissions from Animal Production Buildings
- Munters Italy S.p.a., Chiusavecchia d'Imperia (IM), Italy

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.
The first year of this doctoral activity (that is carried out under co-tutelle agreement with the Universitat Politècnica de València) was characterized by the development (in collaboration with animal scientists of the University of Turin) of robust and reliable energy simulation models for broilers and growing-finishing pigs. 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 livestock houses models were applied to evaluate the influence of the farm management on the energy consumption and to evaluate energy saving strategies. For this purpose, the broiler house model was used to evaluate the extra energy consumption due to an increase of ventilation needed to maintain established gas concentration thresholds. The broiler energy model was also used to evaluate the global primary energy performance for climate control considering broiler houses in different climate conditions and with different envelope solutions.



The analog electrical network used to simulate the greenhouse thermal behavior

During the third year of doctoral activities, the energy simulation model for greenhouses (Fig. 1) was validated against a dataset of monitored data that was collected during a long-term monitoring campaign. Those data were also deeply analyzed highlighting how greenhouses are characterized by a not homogeneous thermal environment.
Another activity that was carried out during the last stage of the doctoral activities was a collaboration with LivAGE Cost Action. This collaboration aimed at exploring the potentiality of RES exploitation inside intensive livestock houses. This is because part of the GHG originated from livestock houses are due to the use of fossil fuels and the adoption of carbon neutral energy sources may contribute to reduce those emissions.

First name: Caio **LAST NAME**: DA COSTA WICHROWSKI

Topic: Analysis of experimental nuclear systems

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

Academic context

[1] C. Di Gesare, D. Caron, S. Dulla, P. Ravetto, M. Carta, V. Fabrizio, Use of new nuclear data libraries for the Monte Carlo analysis of neutronic measurements in the TAPIRO reactor, *International conference PHYSOR 2018*, Cancun, Mexico, April 2018.

[2] E. Gilad et al., Analysis of Critical and Subcritical Neutron Noise Experiments in MINERVE Using Advanced Noise Techniques, *International Conference PHYSOR 2016*, Sun Valley, Idaho, May 2016.

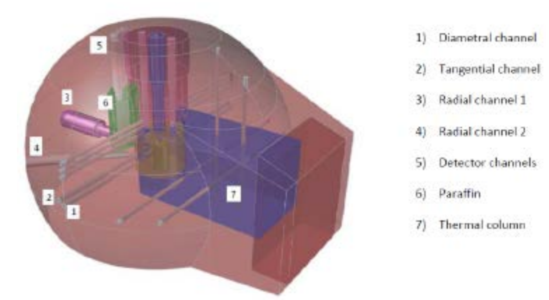
[3] B. Akdeniz, E. Müller, D. Panayotov, K. Ivanov, Consistent Neutron Kinetics Data Generation for Nodal Transient Calculations, *International conference PHYSOR 2006,* Vancouver, Canada, September 2006

External collaborations

- Ben Gurion University of the Negev, Israel
- INFN Genova
- ENEA Casaccia

Highlights of the research activity

In the past year, the main research developed has been related to the field of reactor physics, namely reactor kinetics. The first topic concerns the development of ad-hoc reduced-order models for nuclear reactor analysis and optimization. The main goal has been to reassess methods of calculating the delayed neutron fraction, one of the parameters used to describe and predict the behaviour of a nuclear reactor over time. Together with a long-time collaborator of Politecnico di Torino, Dr. Paolo Saracco (INFN Genova), a new technique for weighting the effective delayed neutron fraction in simplified few energy groups model was proposed, based on a bilinear weighting involving the adjoint function. The results of test calculations evidence the differences between effective and physical values of the delayed neutron fraction. Comparisons between few-group kinetic calculations and reference results based on Monte Carlo based computational simulations of different reactor cores are being carried out. This work generated an abstract submitted and accepted for the International Conference on Physics and Technology of Reactors and Applications (PHYTRA5). Another research focused on the assessment of algorithms for the on-line and off-line reactivity monitoring in critical and subcritical nuclear systems and application to experimental data. The core activity in this case is the application and improvement of a method developed at Politecnico di Torino (MAρTA) to reference transient situations through an inverse kinetics approach combined with tools for the attenuation of space effects based on adjoint weighting of detector signals. Collaborations with IAEA and the Argonne Laboratory have recently provided experimental data over which the method can be applied and compared to computationally simulated experiments. This work has been proposed as part of the activities of an IAEA Coordinated Research Project on Accelerator Driven Systems- Application and use of low-enriched uranium. Finally, in collaboration with ENEA Casaccia, the last topic is the neutronic characterization of the TAPIRO high energy spectrum research reactor and the use of neutronic analysis tools in support of the experimental campaigns. This collaborative initiative with ENEA represents the first attempt to the application of noise analysis methods, with the collaboration of researchers from the Ben Gurion University of the Negev Dr. Erez Gilad, to the TAPIRO reactor, providing a test case for the application of such methods to fast systems.



Irradiation facilities of TAPIRO [1]

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

Topic: Advanced models for the building energy performance assessment

Course year: 2nd **Tutor(s)**: 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 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.

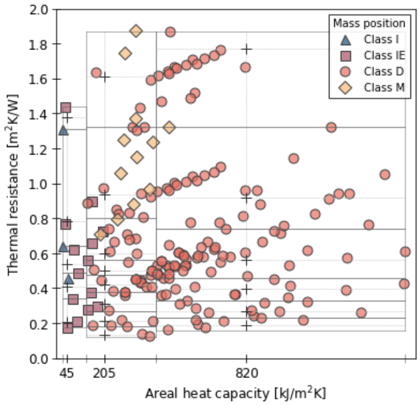
[3] Mirsadeghi, M.; Còstola, D.; Blocken, B.; Hensen, J.L.M. Review of external convective heat transfer coefficient models in building energy simulation programs: Implementation and uncertainty. Applied Thermal Engineering 2013, 56, 134-151.

External collaborations

- EdilClima Engineering & Software
- Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA)

Highlights of the research activity

The issue of improving the energy performance of buildings has led to the rapid development of calculation methods for the energy performance assessment that must comply with the requirements of accuracy, robustness, reproducibility, transparency, and simplicity. To overcome the low accessibility to detailed input data, often required by the detailed calculation models, different simplified dynamic methods have been developed. Among them, the recently introduced EN ISO 52016-1 hourly method is aimed at providing a balanced accuracy and simplification. However, the effects and errors related to the assumptions of the simplified methods have not been sufficiently investigated yet. Thus, the new calculation model has to be validated in terms of its calculation assumptions and simplifications. Within this context, the Ph.D. research proposes an "aware" validation approach, based on three main phases: model in-depth documentation, sensitivity analysis, and validation. The main research activities are focused in developing these phases. The first activity (in-depth documentation) consists in the creation of a "comparison map", in which the specific assumptions of the different calculation methods are described and compared. The conduction through the building envelope and the phenomena involved in the interaction between the outdoor environment and the outside surfaces of the building envelope have been so far deepened. The second activity (sensitivity analysis) is instead focused in identifying the most influencing parameters and/or calculation assumptions on the simulation results. For the analysed case studies, preliminary results reveal that internal gains and building heat capacity have a strong impact on the heating/cooling loads. Finally, the validation of the whole building energy performance calculation method and/or of a specific module is performed in the third activity. The validation of the EN ISO 52016-1 heat conduction model was performed through the comparison with the conduction finite difference solution algorithm and the discretisation model introduced by the Italian national Annex of the technical standard. The simplified method allows to predict the indoor surface temperatures with an accuracy of less than 0.5 °C. Moreover, the EN ISO 52016-1 model has been implemented through the identification of specific pre-calculated values of areal heat capacity and thermal resistance (and respective heat capacity and thermal resistance construction classes) – shown in the attached figure – for the Italian typical construction typologies, to be used in the modelling of the building envelope components whenever the actual value is unknown.



Areal heat capacity and thermal resistance construction classes

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

Topic: Lithium-Ion Batteries (LIBs) degradation.

Course year: 2nd **Tutor(s)**: Pietro Asinari, Daniele Marchisio, Eliodoro Chiavazzo

Academic context

[1] Newman, J.; Tiedemann, W. Potential and Current Distribution in Electrochemical Cells. J. Electrochem. Soc. 1993, 140 (7), 1–5.

[2] Wang, K.; Xing, L.; Zhi, H.; Cai, Y.; Yan, Z.; Cai, D.; Zhou, H.; Li, W. High Stability Graphite/Electrolyte Interface Created by a Novel Electrolyte Additive: A Theoretical and Experimental Study. Electrochimica Acta 2018, 262, 226–232.

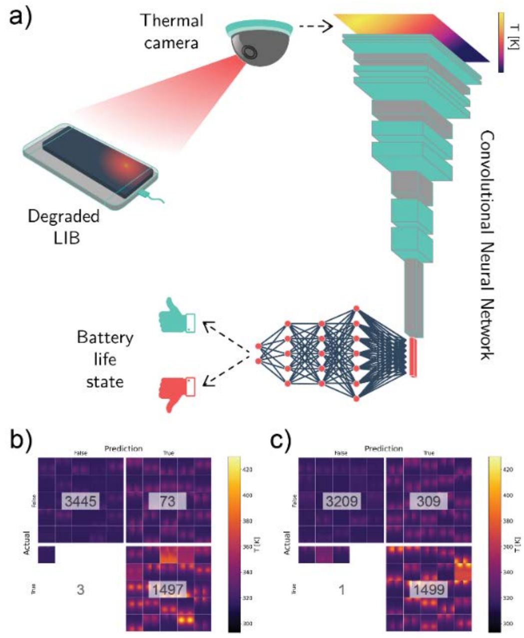
[3] Safari, M.; Morcrette, M.; Teyssot, A.; Delacourt, C. Multimodal Physics-Based Aging Model for Life Prediction of Li-Ion Batteries. Journal of the Electrochemical Society 2009, 156 (3), 145–153.

External collaborations

- Mashayek F. and Yurkiv V. – University of Illinois at Chicago (UIC)

Highlights of the research activity

During my stay at the University of Illinois in Chicago (USA), we worked on forecasting and preventing thermal runaway using Machine Learning (ML) tools. The work was inspired by the idea that in some place where an explosion (already dangerous in its own right) can lead to horrific consequences, like airport and hospitals, a thermal camera capture the temperature of device power by a LIB ad send it to a Deep Neural Network (DNN) to identify temperature pattern change leading to the thermal runaway (figure 1.a). We built our image database by performing multi-physics calculations using the Comsol software package. We set up a virtual experiment considering a system made a pouch type LIB. The electrochemical problem is described in this domain by the set of equations from the Pseduo 2-Dimensional model (P2D) [1]. In addition to the electrochemical, we incle the aging phenomena (SEI growth) using the parasite current approach [2,3]. This parasitic current induces a self-heating phenomenon in a localized region (choose randomly but apriori at the begging of the simulation), which reproduces the thermal runaway. From this model, after sensitivity and a mesh size independence study, I performed about a hundred different simulations that were used to produce the images for our DNN algorithm. At the and I got around 25000 pictures. The DNN architecture used was the Convolutional Neural Network (CNN). This choice was forced since we are dealing with images. To understand, let suppose we used a common Neural network; at the input layer, we need a "neuron" for each pixel. The CNN overcame this issue, reducing the input size by extracting 2000 or more features of the picture by a set of 2D convolutions. In the meantime, I started a new activity in the project big-MAP (https://www.big-map.eu) regarding the study of the SEI.



(a) Representation of a possible application of the algorithms designed in out work, a thermal image of a damaged battery (e.g., a battery of an old smartphone) is sent to the CNN network whit returns the state of the battery with a certain probability. To show the result, we plotted the confusion matrix for the two Neural Network: VGG16 (b) and Xception Net (c).

First name: Alessandro **LAST NAME**: FALAI

Topic: Optimal design and control of Hybrid Electric Vehicles

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

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., and Venditti, M., "Optimization of the Layout and Control Strategy for Parallel Through-the-Road Hybrid Electric Vehicles," SAE Technical Paper 2014-01-1798, 2014, doi:10.4271/2014-01-1798.

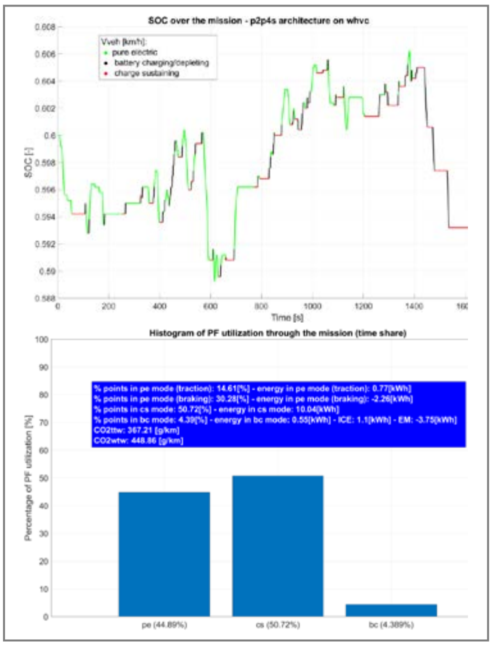
[3] PhD dissertation, Venditti, M., ''Innovative models and algorithms for the optimization of layout and control strategy of complex Diesel HEVs'', Politecnico di Torino, Italy, 2015.

External collaborations

- FPT industrial S.p.A., Italy (IT)
- AVL Italia, Italy (IT)
- FCA Italy (IT)

Highlights of the research activity

In the regard, in industrial project with FPT Industrial, an optimal design tool has been developed in order to evaluate a great number of different hybrid powertrain layouts, defined by a set of parameters that characterizes the powertrain itself according to metric such as fuel consumption and nitrogen oxides emissions and the vehicle total cost of ownership over the lifespan. To make evaluation independent on the controller, the tool evaluates the emissions for each layout according to the optimal control strategy, which is obtained from a global control strategy optimization algorithm based on Deterministic Dynamic Programming (DDP). Since this tool was able to perform only on Parallel HEV, my research activity was to redefine the vehicle's model simulation and control strategy optimization algorithm to the series-type hybrid powertrains. This vehicle model was named p2p4series since the power demand is fully covered by one electric motor mechanically linked to the wheels through the rear axle, while the power group (ICE plus a generator) is electrically linked to the battery. One important benefit for series hybrid architecture is that the internal combustion engine would operate in its high efficiency region. As far as the operating modes (also called Powerflows PFs) are concerned, the three categories under investigation are: pure electric (only electric motor provides the traction power), charge sustaining (engine provides enough power to power the traction electrical motor through the generator) and battery charging/charge depleting (engine is on and provides a fixed power to the battery through the generator). For the sake of brevity, these could be considered as control variables, while the State of Charge (SOC) and the engine speed (ω_{ice}) as state variables as well. The DDP algorithm find the optimal control strategy of a specific layout over a given driving mission, e.g WHVC, minimizing a cost function depending on control and state of the system. The SOC is constrained to 0.6 at the beginning and has to be brought back to this value at the end of the mission. The SOC profile with optimal control strategy is reported in graph for one specific heavy-duty vehicle (3.6L engine, 150kW of both electric motors) with results in term of CO2 tank-to-wheels (histogram).



First name: Gabriele **LAST NAME**: FALCIANI

Topic: Analysis and modelling of future emerging technologies for solar fuel generation

Course year: 1st **Tutor(s)**: Eliodoro Chiavazzo

Academic context

[1] Falciani, Gabriele, et al. "A multi-scale perspective of gas transport through soap-film membranes." Molecular Systems Design & Engineering 5 (2020): 911-921.
[2] Reece, Steven Y., et al. "Wireless solar water splitting using silicon-based semiconductors and earth-abundant catalysts." Science 334.6056 (2011): 645-648.
[3] Lewis, Nathan S. "Research opportunities to advance solar energy utilization." Science 351.6271 (2016).
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External collaborations

- Uppsala University
- International Center for Theoretical Physics - ICTP
- Teclis Scientific

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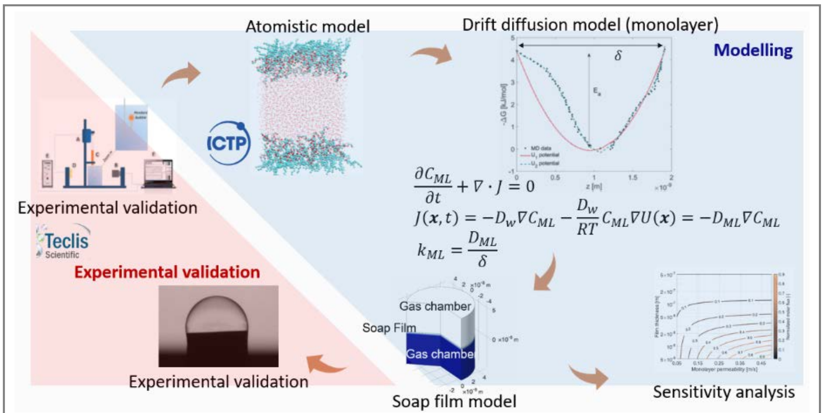
Highlights of the research activity

My PhD is part of a wider European project called Sofia (grant agreement No. 828838), which aims at developing a proof-of-concept device for converting solar energy and carbon dioxide directly into clean fuels exploiting the unique self-assembling property of surfactants and proton transport properties of soap films. In this context, the aim of my research studies is to set-up an innovative multiscale and multiphysics model that will accurately describe and predict the performance of the new photosynthetic membranes used in the future device.



Multiscale model for calculating gas permeation across soap film membranes [1].

A soap film membrane presents sandwich structure where a water core is stabilized by two surfactant monolayers. In the case of the Sofia project, this engineered membrane separates two compartments initially filled with carbon dioxide. When light shines on it, the two half-reactions of fuel production (CO/H_2 mixture) and oxygen evolution (oxygen is a byproduct of the process) occur on the two opposite faces of the soap film that separates the produced gases. However, these gases will tend to diffuse from one side to the other of the membrane driven by the presence of a concentration gradient. Hence, it is crucial for the membrane to keep separated the gases generated in the two compartments long enough to allow their storage.
During my first year, I set-up a model to investigate the gas permeation dynamics across soap film membranes. First, I implemented the diffusion continuum model and I benchmarked it with experimental data from the literature. This model can be used for sensitivity analysis to investigate how the various properties of the membrane influence the gas transport. Afterwards, I have developed a multi-scale method where molecular dynamics details, obtained from our partner ICTP, are used to derive parameters for a drift diffusion model at continuum level to describe the interactions between the permeating gases and the surfactant monolayers. Our model was benchmarked against experimental data from our partner Teclis Scientific. Details can be found in our recently published paper [1] that got outside front cover of the Journal.
Finally, my main task in the next academic year will be to implement reaction kinetics in the existing diffusion model to comprehensively describe the solar to fuel process.

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

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

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

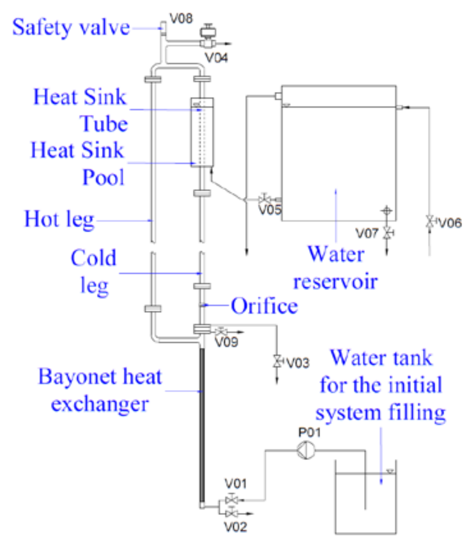
Academic context

[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, Journal of Physics: Conference Series, Volume 1599
[2] International Atomic energy Agency, Advances in Small Modular Reactor Tecnology Developments. A supplement to IAEA Advanced Reactors Information System (ARIS), 2020 Edition
[3] U.S. Nuclear Regulatory Commission, International Agreement Report - Assessment of the Wall Film Condensation Model with Non-condensable gas in RELAP5 and TRACE for Vertical Tube and Plate Geometries, 2019

External collaborations

Highlights of the research activity

During the third year of PhD activity, the study of passive heat removal systems based on natural circulation has been continued. The PROPHET2 experimental facility built at Politecnico di Torino has been used to perform a new experimental campaign aimed at the verification of the repeatability of the experimental test matrix performed in the past and at the realization of new experimental tests. Several experimental tests has been performed for different values of the initial water inventory inside the loop and of the gross electric power provided to the electric heater, operating the facility in both single- and two-phase natural circulation. This allowed to study the effect of the different initial and boundary conditions on the start-up phase of the natural circulation and on the operation at almost steady conditions. Considering tests in single-phase natural circulation regime, the effect of the power level on the mass flow rate and on the buoyancy driving head at the end of the transient has been investigated.



PROPHET2 test facility.

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

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

Course year: 2nd **Tutor(s)**: Marco Badami

Academic context

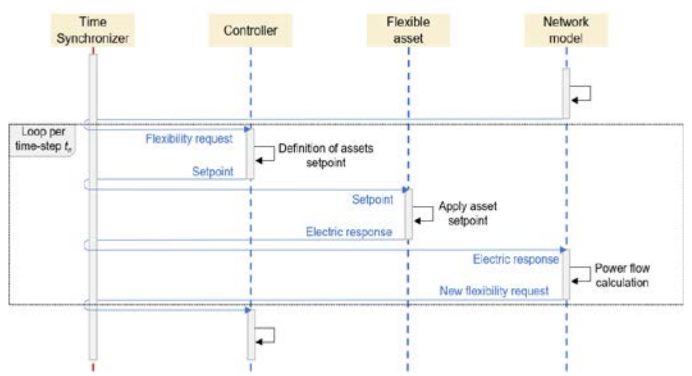
[1] Badami M, Fambri G. Optimising energy flows and synergies between energy networks. Energy, 2019,173,400-412.
[2] Badami M, Fambri G, Mancò S, Martino M, Damousis IG, Agtzidis D, Tzovaras D. A Decision Support System Tool to Manage the Flexibility in Renewable Energy-Based Power Systems. Energies. 2019;13(1):153.
[3] Fambri G, Badami M, Tsagkrasoulis D, Katsiki V, Giannakis G, Papanikolaou A. Demand Flexibility Enabled by Virtual Energy Storage to Improve Renewable Energy Penetration. Energies. 2020; 13(19), 5128.

External collaborations

- CERTH - Centre for Research and Technology Hellas, Thessaloniki (Greece)
- Hypertech Energy Labs, Hypertech, Chalandri (Greece)
- VTT - Technical Research Centre of Finland, Espoo, (Finland)

Highlights of the research activity

My research activity carried out during the second year of PhD was mainly performed within the EU H2020 project PLANET (Planning and operational tools for optimising energy flows & synergies between energy networks). PLANET is developing a holistic Decision Support System (DSS) for the simulation of multi-energy system scenarios in order to analyse and optimize renewable energy integration by taking advantage of the flexibility offered by energy storage and conversion technologies.
In summary, my research work can be divided in three different main activity as detailed in the followings:
i) development of communication systems between the various modules of the PLANET DSS. The DSS has been developed with a co-simulation architecture in which the different modules, developed in different programming languages / computing environments (Python, MATLAB, Simulink and RT-Lab), are located in remote machines. The co-simulation of the different modules makes DSS very flexible and scalable, as each module can easily be modified or replaced in a plug and play fashion. For each module, a submodule for MQTT communication was created in order to create a unified communication framework;
ii) development of logics and controls for the automation and coordination of data exchanged between DSS modules. In order to coordinate the messages exchanged between the various modules, an additional module has been created, called Time Synchronizer (TimeSync) which has the task of receiving all the messages that are sent by the various modules, and dispatching them in the right order to the receiving modules.
iii) utilization of the above described co-simulation based DSS for the analysis of multi-energy system scenarios. This activity led to the publication of 3 papers: 1 conference paper (“*A Real-Time Based Platform for Integrating Power-to-Gas in Electrical Distribution Grids”,* UPEC, IEEE, 2020) and 2 journal papers (“*A Decision Support System Tool to Manage the Flexibility in Renewable Energy-Based Power Systems”,* Energies 2019. “*Demand Flexibility Enabled by Virtual Energy Storage to Improve Renewable Energy Penetration*”, Energies 2020).



Main information flows of the co-simulation process.

First name: Giovanni **LAST NAME**: GENNARO

Topic: Performance characterization and control strategies of Double Skin Facades

Course year: 1st **Tutors**: Marco Perino, Fabio. Favoino

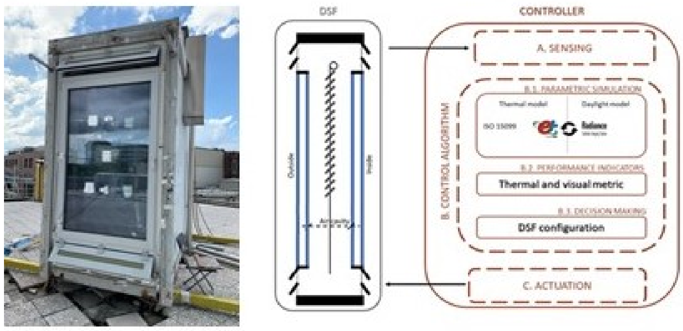
Academic context

[1] Loonen R.C.G.M., Favoino F., Hensen J.L.M., Overend M., *Review of current status, requirements and opportunities for building performance simulation of adaptive facades*. Journal of Building Performance Simulation, 10, 2017;
[2] Catto Lucchino E., Goia F., Lobaccaro G., Chaudhary G., *Modelling of double skin facades in whole-building energy simulation tools: A review of current practices and possibilities for future developments*. Building Simulation 12, 2019;
[3] Bueno B., Street M., Pflug T., Braesch C., *A co-simulation modelling approach for the assessment of a ventilated double-skin complex fenestration system coupled with a compact fan-coil unit*. Energy and Buildings, 151, 2017;

External collaborations

EURAC Research (Dr. G. De Michele), Norwegian University of Science and Technology (NTNU)

Highlights of the research activity



DSF mock-up (left) Model-based control workflow (right)

Double Skin Facades (DSF) are complex fenestration systems used to actively manage different tasks (solar gains, ventilation and daylight) in buildings, thus impacting on energy use and occupant comfort. The performance of such adaptive systems is strictly dependent on control strategies adopted during building operation and therefore, the development of advanced control algorithms which allow to meet multiple performance requirements is of outermost importance. The research activity is aimed at developing a reliable toolchain for the analysis of the performance and the implementation of control strategies in Double Skin Facades. The first year of the PhD has been characterized by both simulative and experimental activities. The simulation activity focused on the definition of the optimal building energy simulation tool, able to properly characterize the physical behavior of DSF integrated in a whole building. For this purpose, several activities have been carried out: (i) exploring the ability of three best suited Building Energy Simulation (BES) tools (i.e. EnergyPlus, IDA ICE and TRNSYS18) to simulate ventilated DSFs; (ii) implementation and calibration of a reduced numerical model based on ISO 15099 (for co-simulation with above BES tools); (iii) implementation and calibration of the Five-Phase Method of Radiance, to perform point-in-time daylighting simulations. Finally, the accurate thermal and optical model of the DSFs has been employed to perform annual simulations of the whole building and to design and test different control strategies suitable for different building contexts.
A yearly measurement campaign has been carried out with the TWINS facility of DENERG in which an extremely flexible DSF is installed (Figure 1), reproducing the different kinds of DSF: capable of varying the air-path (between outdoor and indoor environment), air velocity (natural and mechanical ventilation) and controlling solar shadings. Experimental characterizations of the different DSF configurations were first carried out, with the aim to calibrate the different DSF models and to derive Key Performance Indicators useful to quantify the impact of the facade configuration on the internal space. Finally, a model-based IoT controller has been devised and built: a Raspberry Pi 4 performs the tasks shown in [Fig. 1] (sensing, simulating, deciding, actuating the control). In this flexible framework we will be able to implement different thermal models (white-box models, reduced or data driven models) and control algorithms (rule-based and predictive controls).

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

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

Course year: 3rd **Tutor(s)**: Mirko Baratta, Daniela Anna 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] Goel, P., Baratta, M., Misul, D., Christou, P., Ravet, F., “Mixture formation and combustion behaviour analysis in a DI NG engine with centrally mounted injector under different injection timings”, International journal of mechanics and control, Vol. 21, No. 01, 2020.
[3] Baratta, M., Chiriches, S., Goel, P., Misul, D., “CFD modelling of natural gas combustion in IC engines under different dilution and H2-doping conditions,” Transportation engineering, Vol 2, 2020, https://doi.org/10.1016/j.treng.2020.100018.

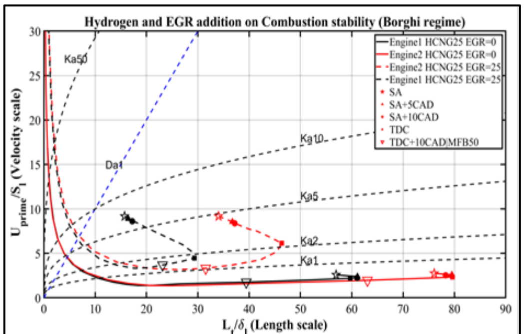
External collaborations

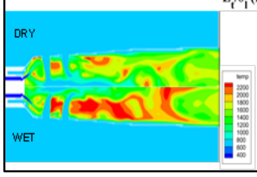
- Renault Technocenter, France
- IFP Energies Nouvelles, France
- ETHOS Energy Italia, Italy

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 such as laminar flame speed sub-model to improve the numerical combustion accuracy. 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 with research already published [1,2].

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 has been published [3].





Effect of hydrogen and EGR on addition combustion stability (above), TG20 burner results with wet case.

Along with the activity mentioned above, a research project has been started with Ethos Energy, with the objective to characterize the combustion and emissions of the TG20 gas turbine burner with respect to available experimental data. 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 has been extended to understand the effect of water addition in combustor and its effect on NOx. This activity is ongoing and will be finalized in 2021.

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

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

Course year: 2nd **Tutor(s)**: Stefano P. Corgnati, Stefano Lo Russo

Academic context

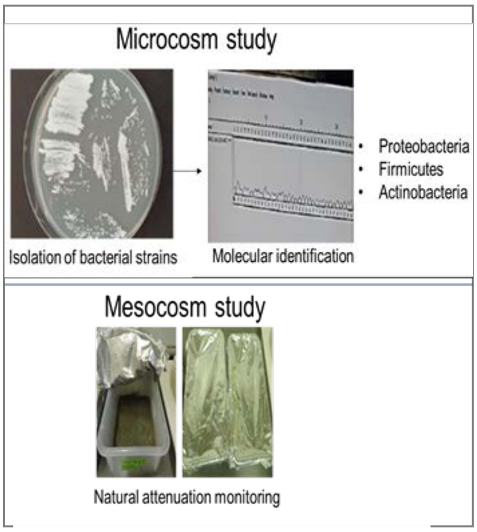
[1] Xu X, Liu W, Tian S, Wang W, Qi Q, Jiang P, Gao X, Li F, Li H, Yu H (2018) Petroleum Hydrocarbon-Degrading Bacteria for the Remediation of Oil Pollution Under Aerobic Conditions: A Perspective Analysis. Front. Microbiol. 9:2885.
[2] Borah Debajit and Yadav R N S. Bioremediation of petroleum-based 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, Via Maritano 26, 20097 San Donato Milanese

Highlights of the research activity

The systematic use of petroleum for energy supply and goods manufacturing enables to fulfill human needs. However, this has engendered massive environmental pollution threatening not only soil and aquatic ecosystems but also human health.
At the forefront of remediation approaches, bioremediation exploiting the natural abilities of micro-organisms to metabolize pollutants offers an efficient, eco-friendly and cost-effective means to tackle this issue.
In this framework, the study aims to develop highly efficient microbial consortia usable in the decontamination of hydrocarbon-polluted environments, aiming at re-using the area after the bioremediation for clean energy purposes too.
The experimental research activities had been designed as a four-steps experimental process involving the isolation of bacteria fromhydrocarbon-contaminated soil samples, selection of isolates presenting efficient bioremediation potential, constitution of consortia and study in mesocosms. The objectives to be achieved for this second year included the assessment of consortia efficiency and monitoring of bioaugmentation in contaminated matrices. However, due to the ongoing Covid-19 pandemic, the laboratory access has been limited, making it unfeasible to achieve them. Despite these drawbacks, bacteria have been isolated from contaminated soil samples and identified on the molecular level. The results indicated the dominance of Gammaproteobacteria among the isolates; suggesting the presence of hydrocarbon degraders and a natural biodegradation ongoing. Preliminary tests have also been conducted in order to assess the isolates potential for bioremediation. The results are not conclusive at the time being.
For further assessment of the efficiency of consortia once inoculated in contaminated matrices, a natural attenuation mesocosm has been set up and is under monitoring.



Bacteria identification and natural attenuation

More so, a first bioaugmentation assay has been recently set up. Deeper assessment of the isolate's bioremediation potential is still needed, as well as assessment of consortia efficiency. Lastly, during this second year a course on life cycle assessment has enabled to inform the research on sustainability studies.

First name: Giulia **LAST NAME**: GRISOLIA

Topic: Biofuels and bioplastics from micro-organisms: thermodynamic and thermoeconomic analysis of sustainability

Course year: 1st **Tutor(s)**: Umberto Lucia, Debora Fino

Academic context

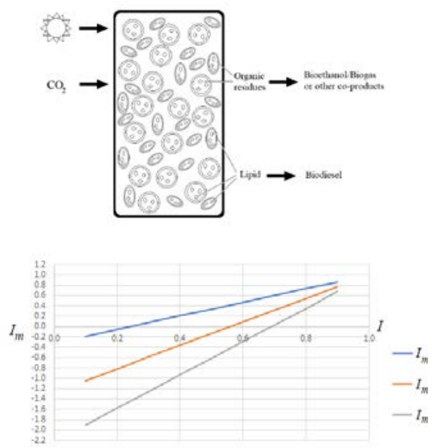
[1] G. Grisolia, D. Fino & U. Lucia. Thermodynamic optimisation of the biofuel production based on mutualism. *Energy Reports* 2020, **6**, 1561-1571.
[2] U. Lucia & G. Grisolia. How Life Works – A continuous Seebeck-Peltier Transition in Cell Membrane?. *Entropy* 2020, **22**, 960.
[3] U. Lucia & G. Grisolia. Thermal resonance and cell behaviour. *Entropy* 2020, **22**, 774-785.

External collaborations

- Harvard-MIT Martinos Center for Biomedical Imaging, Massachusetts General Hospital and Harvard Medical School, Charlestown, MA 02129, USA
- Joint Institute for Nuclear Research, 141980 Dubna, Moscow Region, Russia
- Ibaraki University, Mito 316-8511, Japan

Highlights of the research activity

Some recent issues as the global climate change, the biodiversity loss, the Oceans and the local pollution, are only the tip of the iceberg of a more complex problem which involves all relevant aspects of our society and highlights that the actual path is no more sustainable. On these bases, *research* plays a crucial role to provide effective solutions to guarantee the well-being for the future generations. These solutions must be achieved by considering the three domains of sustainability - environment, economy and society - all together. But, how can we assess effective sustainability? A set of metrics (*sustainability indicators*) are needed, in order to evaluate the present conditions in relation to the past ones, to develop the guidelines for the next future and to assist policy-makers and stakeholders in their choices towards sustainability. Thus, the first year of my PhD research activity has been focused on the definition of a thermoeconomic indicator, with the aim to introduce a new thermodynamic approach into bioeconomy. The indicator proposed is based on *energy intensity*, *labour productivity* and on the *Second Law analysis*. Indeed, the first goal of the PhD activity was set in order to obtain a thermoeconomic way to evaluate sustainability in relation to entropy generation, considering both the human conditions and the consequences of the production activities on climate and weather. In this context, biofuels production by micro-organisms has been analysed, in order to suggest biofuels use in energy sector as a possible response to the needs of the sustainable development. To improve the biofuels production by micro-organisms, the mutualism between different species, has been proposed and, the indicator has been evaluated by using literature data. To produce biodiesel, the useful quantity is the amount of lipids which can be collected from the biomasses. The indicator is proportional to the lipid mass and, the mutualistic indicator I_m results always lower than the non-mutualistic one (I), being $I < 1$. $I_m = I + (I - 1)\,\Delta m/(m_1 + m_2)$, where m_1 and m_2 are the lipid masses of the two co-cultured species (if cultivated independently), Δm is the increase in lipid production due to mutualism. In Figure, I_m vs I is represented. It is possible to highlight that mutualism represents an improvement in biofuels production, being more sustainable, due to its lower value.



Co-culture of two different micro-organisms performing symbiosis, and indicator in mutualistic (I_m) vs non-mutualistic (I) conditions. Mutualism results more sustainable due to its lower value.

First name: Fabrizio **LAST NAME**: GULLINO

Topic: Advanced Powertrain Solutions for Environmentally Friendly Hypercars

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

Academic context

[1].Millo, F., Rolando, L., Zanelli, A., Pulvirenti, f., Cucchi, M., Rossi, V., ''A Methodology for Modeling the Cat-Heating Transient Phase in a Turbocharged Direct Injection Spark Ignition Engine'', SAE Technical Paper 2017-24-0010, 2017, doi: 10.4271/2017-24-0010;
[2].Paltrinieri, S., Mortellaro, F., Silvestri, N., Rolando, L. et al., "Water Injection Contribution to Enabling Stoichiometric Air-to-Fuel Ratio Operation at Rated Power Conditions of a High-Performance DISI Single Cylinder Engine," SAE Technical Paper 2019-24-0173, 2019, doi: 10.4271/2019-24-0173;
[3].Bozza, F., Tufano, D., Malfi, E., Teodosio, L. et al., "Performance and Emissions of an Advanced Multi-Cylinder SI Engine Operating in Ultra-Lean Conditions," SAE Technical Paper 2019-24-0075, 2019, doi: 10.4271/2019-24-0075.

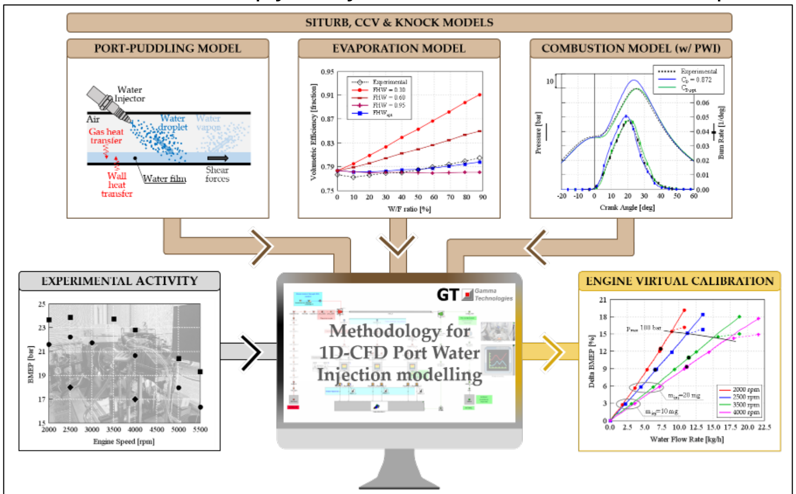
External collaborations

- Ferrari Know-How and Simulation department, www.ferrari.com
- Gamma Technologies LLC, www.gtisoft.com
- Centro Ricerche Fiat (CRF), www.crf.it

Highlights of the research activity

The research activity aims to develop a quasi-dimensional virtual test rig with the objective to quantify the potential benefits in terms of greenhouse gases and criteria pollutants reduction of different engine technologies (e.g. Water injection, Turbocharger electrification, Miller cycle, Lean combustion with pre-chamber, etc...) and aftertreatment configurations over RDE cycles for high-performance SI engines.

The 1st year activity has been focused on Water Injection. After an extensive literature review, the experimental outcomes of a test campaign carried out on a Turbocharged Direct Injection Spark Ignition (T-DISI) engine modified for Port Water Injection (PWI) were collected and deeply analyzed. These data were then exploited to develop a quasi-dimensional model of the PWI system. Taking into account the Cycle-to-Cycle Variability (CCV), the water wall film formation and the effect of water on the Laminar Flame Speed (LFS) slowing (see Figure 1), this methodology allows to assess PWI knock mitigation potential, thus significantly reducing the experimental effort for engine calibration. Moreover, it will be fundamental to determine the water consumption as well as the potential benefits in terms of CO_2 emissions achievable over RDE cycles.



Development of a methodology for the assessment of knock mitigation potential of PWI in a T-DISI engine

[1]: Millo, F.; Gullino, F.; Rolando, L. "Methodological Approach for 1D Simulation of Port Water Injection for Knock Mitigation in a Turbocharged DISI Engine". Energies 2020, 13, 4297.

This activity was summarized in a journal article published in August 2020 [1] and presented both at the 'SAE - CO2 Reduction For Transportation Systems Conference' (July 2020) and at the 'Global GT conference' (October 2020).

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

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

Course year: 2^{nd} **Tutor(s)**: Alessandro Ferrari

Academic context

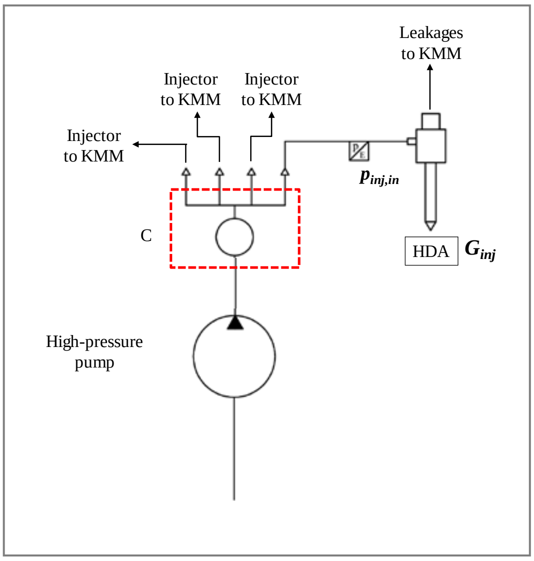
[1] Ferrari A, Mittica A, Pizzo P, Jin Z. 2018. PID controller modelling and optimization in Cr systems with standard and reduced accumulators. International Journal of Automotive Technology.
[2] Ferrari A, Jin Z, Mittica A, Vento O, Zhang T, Ouyang L, Tan S. 2019. Application of the common-feeding injection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

External collaborations

- Nanyue Fuel Injection Systems Co., Ltd

Highlights of the research activity

With the objective of developing a new CR system without rail, for Chinese market, Nanyue Fuel Injection Systems Co. Ltd has financed a project. This idea is based on a patent recently made at Politecnico. The new prototype of the fuel injection system has the benefits of lower manufacturing costs and easier installation on the engine compared with a traditional Common Rail system. In order to analyze the rail size effect on injection performance, experimental tests have been performed and the data has been collected for rails of different volumes. The results have been analyzed and compared. It can be concluded that, in general, when the rail size or shape is varied, the injection performance is kept. The practical results have been submitted to the conference of ASME ICEF 2019 and the paper has been accepted.
The second project is related to an innovative injected quantity estimation method that was applied to a passenger car common-rail (CR) injection system. This has been realized by means of time-frequency analysis applied to the short time Fourier transform (STFT) of the pressure signal captured by one transducer along the rail-to-injector pipe. With this input pressure time history, the injection temporal length (ITL) could be obtained by detecting the start and the end of the hydraulic injection. By applying the values of the nominal rail pressure and the ITL, the estimated injected mass (M_{inj}) could be evaluated with a determined correlation. Finally, 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 which features an overall error within 1.5 mg.
Finally, I have been involved in a research activity on the combustion noise in the design of modern diesel engines. This project has been focused on identifying different combustion stages along the whole combustion phase for various injection strategies to offer a way to evaluate the contribution of each event to the overall combustion noise by means of time frequency analysis. Choi-Williams distribution has been selected to treat the in cylinder pressure signal. By applying two filters which stand for the frequency attenuation of the human hearing system and engine block to the evaluated frequency spectrum, the combustion noise could be computed. This technique can be optimized and applied as a diagnostic tool for real control or for the refinement of combustion system design.



First name: Daniele **LAST NAME**: LEREDE

Topic: Progressing in the assessment of the role of nuclear fusion in the future energy mix

Course year: 1st **Tutor(s)**: Laura Savoldi

Academic context

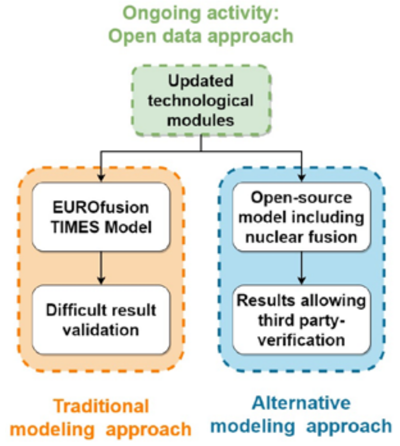
[1] D. Lerede et al., "Analysis of the Effects of Electrification of the Road Transport Sector on the Possible Penetration of Nuclear Fusion in the Long-Term European Energy Mix", Energies, vol. 13 (14), 3634, 2020.
[2] J. F. DeCarolis, "The case for repeatable analysis with energy economy optimization models", Energy Economics, vol. 34, pp. 1845-1853, 2012.
[3] Cabal, H. et al., "Fusion power in a future low carbon global electricity system", Energy Strategy Reviews, vol. 15, pp. 1-8, 2017.

External collaborations

- EUROfusion
- Consorzio RFX
- ENEA

Highlights of the research activity

The research activity "Progressing in the assessment of the role of nuclear fusion in the future energy mix" is devoted to the improvement of methods for the energy modeling involving long-term projections to include nuclear fusion power plants for electricity production, through the "Alternative modeling approach" sketched in Figure 1. In order to better open the black-box of energy modeling tools, the first part of the year has been dedicated to the study of the mathematics behind the TIMES model generator and its structure. In TIMES, the interconnections between energy supply and demand are organized in the Reference Energy System, a network built at each time-step in order to minimize the total cost of the energy system during the model time horizon. The currently implemented cost optimization algorithm limits the capabilities of the model to identify alternative pathways for the development of the energy system. Since TIMES uses proprietary software for both the solution of the optimization problem and graphic interface, this information will be exploited for the development of an open-source model, with the additional possibility to switch and combine different alternative solution strategies. The identification of alternative solution strategies has been analyzed in the past months by coupling the ETM deterministic outcomes with a Multicriteria Decision Analysis tool, the Stochastic Multi-objective Acceptability Analysis (SMAA), in order to identify the most suitable criteria for the an energy system model. In parallel, some time has been devoted to the preparation of a paper about the review and update of the road transport sector in the EUROfusion TIMES Model (ETM). The main outcomes of the scenario analyses identified how a significant update of transport technologies, also considering innovative technologies, has a strong effect in improving the robustness of the results of ETM. The second part of the year has been dedicated again to the maintenance of the ETM model, carrying out a massive update of its industry sector, for the complete technological review of five energy-intensive industrial subsectors and micro-CHP plants, of the hydrogen module, of the base year industrial module calibration and of the demand elasticities to match actual industrial production statistics. Energy scenarios subsequent to the industry module update, despite the large number of technologies and parameters either deeply reviewed or added from scratch, has not identified a complete twisting in industrial energy use projections, but provided a broad picture of the innovations in the sectors which are now included in an existing macro-scale model, and increased the reliability and robustness of model projections.



Plan for open-source implementation of an energy model including nuclear fusion

First name: Carola **LAST NAME**: LINGUA

Topic: New approaches and economic-financial models to support technological innovation in the building energy sector

Course year: 1st **Tutor(s)**: Stefano Corgnati, Cristina. Becchio, Marta Carla Bottero

Academic context

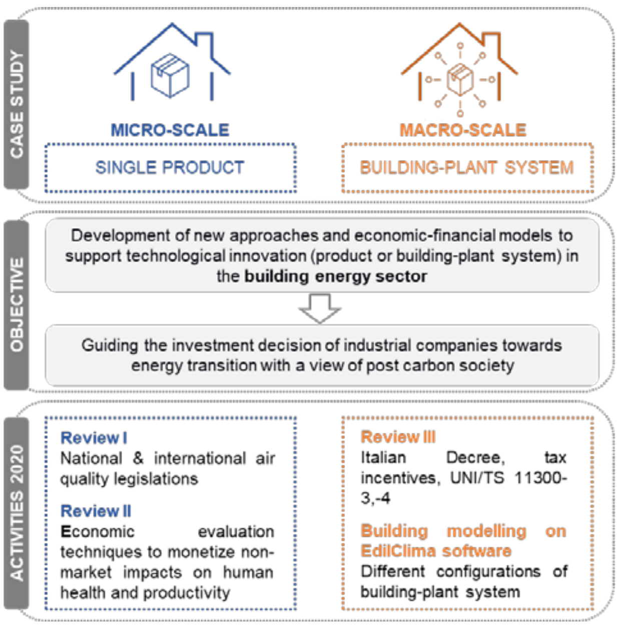
[1] European commission 2014. Guide to Cost-Benefit Analysis of Investment Projects: Structural Funds, Cohesion Fund, and Instrument for Pre-Accession. Directorate-General for Regional Policy, Brussels.
[2] Kougea, E., and Koundouri, P. Air Quality Degradation: Can Economics Help in Measuring its Welfare Effects? A Review of Economic Valuation Studies. DEOS Working Papers from Athens University of Economics and Business, 1129.
[3] Fisk, W. and Seppanen, O., 2007. Providing better indoor environmental quality brings economic benefits. Proceedings of Clima 2007 Well Being Indoors, June 10-14, 2007, Helsinki.

External collaborations

- RHOSS S.p.A., Codroipo (UD), Italy
- ANNEX 79 community, Occupant behavior-centric building design and operation EBC
- PRIN, Next.com project consortium

Highlights of the research activity

The importance of indoor environmental quality for occupant's well-being, health and productivity has been emphasized in recent years becoming one of the main goals during the building design process and operation. In particular, the topic is increasingly being explored due to the introduction of the new Smart Readiness Indicator (SRI) by the revised Energy Performance of Building Directive (EPBD, 2018), as well as the spreading of the coronavirus disease pandemic. The main objective of my PhD research concerns the development of new approaches and economic-financial models to support technological innovation in the building energy sector, guiding the investment decision of industrial companies towards energy transition with a view of post carbon society. The activities have been developed on two main scales: the micro-scale (individual product) and the macro-scale (building-plant system). About micro-scale, the first year of PhD has been dedicated to review the main air quality legislations at the international and national level, identifying the concentration threshold of indoor and outdoor pollutants in indoor environments. Furthermore, a deep review on economic evaluation techniques to monetize non-market impacts (e.g. air quality) on human health and performance was achieved. Concerning the macro-scale, the activity regarded a first analysis on the new Italian Decrees about tax incentives (e.g. Superbonus 110%) and, subsequently, the modelling of a residential building, with different and innovative typologies of plant system configurations. The simulation software EdilClima EC700 has been used with the aim of investigating how investment alternatives change with or without the incentives. Both scales were investigated thanks to a collaboration with Rhoss S.p.A., an Italian company specialized in the design and management of HVAC systems.



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

Topic: (P)HEV Optimal Design (Interdepartmental Center for Automotive Research and Sustainable mobility@PoliTO (CARS))

Course year: 2nd **Tutor(s)**: Daniela Anna Misul, Ezio Spessa

Academic context

[1] 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.
[2] Anselma, P. G., Maino, C., Musa, A., THEO: a tailored hybrid emission optimizer for the drivers of tomorrow, TRAVISIONS 2020 Young Researchers Competition, Road Winner. https://www.travisions.eu/TRAVisions/javax.faces.resource/files/2020/students/road_1.pdf.xhtml?ln=travisions.
[3] Hu, Y., Li, W., Xu, K., Zahid, T., Qin, F., & Li, C. (2018). Energy management strategy for a hybrid electric vehicle based on deep reinforcement learning. Applied Sciences, 8(2), 187.

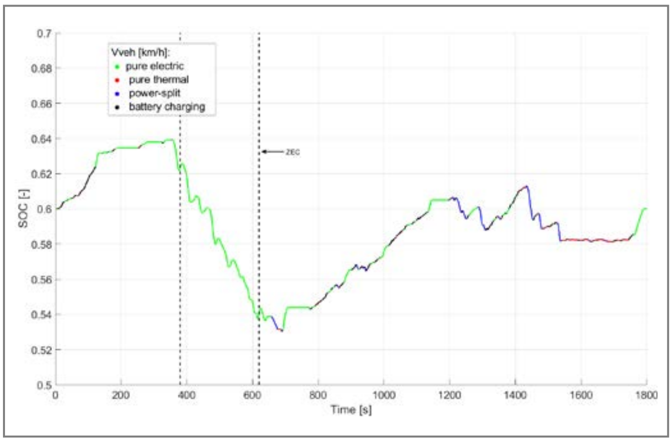
External collaborations

- FPT Industrial
- AVL Italia S.r.l
- Addfor S.p.a

Highlights of the research activity

Development of an innovative tool for performing design optimization of hybrid vehicles fleets (research project in collaboration with FPT Industrial)
Several features have been introduced into a HEV design optimization tool developed during my first PhD year to enhance the simulation capabilites:

- Enlargement of the (P)HEV architectures available for the simulations
- Massive testing of the DoE-based design optimization procedure
- Detailed analysis of the tool robustness during simulations of extreme HEV layouts
- Enlargement of post-processing utilities
- Development of a tool with the capability of optimizing the design and control of Plug-in HEV (PHEV)
- Development of a DP-based optimization algorithm with the capability of defining an optimal control strategy for a (P)HEV on a driving mission featured by zero emission zones (ZEC, see Fig.1).



Battery state of charge trajectory resulting from the DP-based optimal control strategy defined for a P2 HEV simulated on the WHVC including a ZEC zone.

Development of a real-time tailored HEV emission optimizer based on Deep Learning algorithms
A real-time control optimizer for HEVs based on Long-Short Term Memory Neural Networks (LSTM) has been developed and tested within a research project concurring for the Young Researchers competition of TRAVISIONS 2020 and resulting winner of the road transport category. The LSTM-based HEV controller has been trained on the optimal control trajectories defined by a CO2-minimization-based DP algorithm for several experimental driving missions. Once the learning process has been completed, the controller has been tested on unknown driving scenarios, proving the potentials of making real-time decisions comparable to the DP optimal ones.

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: 2nd **Tutors**: Stefano d'Ambrosio, Roberto Finesso

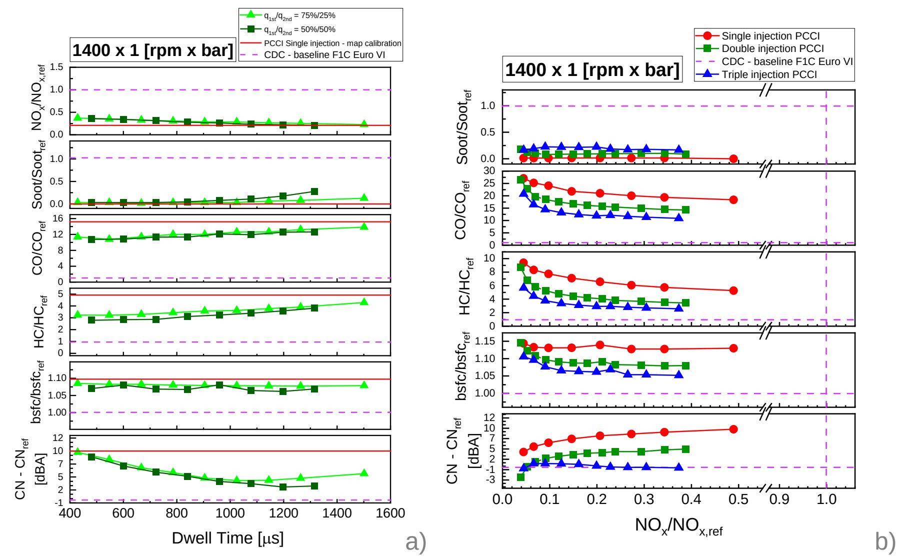
Academic context

[1] Experimental analysis on the effects of multiple injection PCCI strategies on pollutant emissions, combustion noise and fuel consumption in a 3.0 l diesel engine / S. d'Ambrosio, G. Hardy, A. Manelli, A. Mancarella, A. Mittica (submitted to SAE International Journal of Engines)
[2] Model-based control of torque and nitrogen oxide emissions in a Euro VI 3.0L diesel engine through model-in-the-loop / Manelli, Andrea; Finesso, Roberto; D'Ambrosio, Stefano; Ventura, Loris. - ELETTRONICO. - 2191(2019), p. 020105. (Intervento presentato al convegno 74° Congresso Nazionale ATI tenutosi a Modena nel 2019).
[3] Model-based design of closed loop controllers of the air-path in a heavy duty diesel engine / Ventura, Loris; Finesso, Roberto; Malan, Stefano A.; D'Ambrosio, Stefano; Manelli, Andrea. - ELETTRONICO. - 2191(2019), p. 020152. (Intervento presentato al convegno 74° Congresso Nazionale ATI tenutosi a Modena nel 2019).

External collaborations

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

Highlights of the research activity



Emissions for double a) and triple b) PCCI injection patterns

During this year, my research activity has been focused on the testing of different PCCI split injection strategies, the installation of a 2.3L diesel Euro VI F1A FPT engine and, finally, the development of a 4 feedback combustion process controller.
Different PCCI split injection strategies have been tested, evaluating the benefits in terms of fuel consumption, combustion noise and pollutant emissions with respect to early single injection PCCI strategy and conventional diesel combustion mode (CDC). Multi-pulse injections have been investigated, in particular double and triple injection patterns, sweeping the fuel injection timing (SOI) and the fuel injection quantity, i.e. the weight of each pulse. Concerning the third activity, a combustion controller of torque and MFB50, which was created and tested in the past years, is currently being refined and enhanced in order to have four distinct and independent control loops (one for each cylinder) which are regulated by PI compensators. It is aimed at reducing cylinder imbalances and the drift caused by the aging of the engine.

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

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

Course year: 2nd **Tutor**: Massimo Santarelli

Academic context

[1] A. Maheshwari, M. et al, “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, et al, “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.

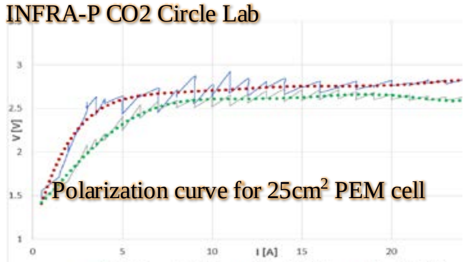
External collaborations

- SINTEF (Stiftelsen for industriell og teknisk forskning), Trondheim, Norway
- CERTH (Ethniko Kentro Erevnas Kai Technologikis Anaptyxis), Thermi Thessaloniki, Greece
- KTH Royal Institute of Technology, Stockholm, Sweden.

Highlights of the research activity

My research aims to have a thorough control on the performance of novel technologies of power to power (P2P) storage by studying the degradation of each of the system’s elements i.e.: batteries, FC/Electrolyser and H_2-based energy storage system. In the second year the main point of focus was on preparing an experimental test rig for carrying out experiments in order to create empirical or semi-empirical degradation models coming from the large amount of collected data. The test rig is assembled at Environment Park and aims at the characterization and performance evaluation of electrochemical devices for production and utilization of H_2, but also including the auxiliaries appliances like the support Li-ion batteries. It is designed to enable low temperature electrolytic devices both with anionic electrolyte such as alkaline cells and with cationic electrolyte such as proton-exchange membrane cells and can test both individual electrolytic cells and cell stacks. To be able to deeply study the degradation phenomena starting from the technology level in each P2P system component - specifically in the electrolyzer- accelerated experimental degradation tests were designed. After the assembly finish, the test rig was tested to be fully functional enabling long term degradation tests. Since for being able to analyze the experiments fully it is necessary to perform the accelerated tests on single cells, research has been done on the type of the necessary cells. Commercial MEA with acidic chemistry was chosen and in order to have the maximum information about the cells, MEA are assembled in the laboratory using the separated anode and cathode side. An industry standard Nafion membrane was used. Anode catalyst for oxygen evolution reaction and flow field are chosen to be IrRuOx with 3-4 mg/cm^2 loading and Platinized titanium based metallic flow field - which is directly applied on the Nafion membrane-. Cathode catalyst and gas diffusion layer are chosen to be Pt black with 3-4 mg/cm^2 and a micro-porous layer respectively. The aforementioned single cells were put under test inside a 5X5cm housing. An initial polarization curve of the cell shows the correct functioning of the cell and the assembled test bench. Following steps are continuing tests on different cells as well as studies on irreversible phenomena inside the cells using voltage-current polarization curves, electrochemical impedance spectroscopy (EIS) and a final post mortem XRD/ SEM analysis.

Electrochemical test bench installed at Environment Park of Turin as part of the INFRA-P CO2 Circle Lab



Polarization curve for 25cm² PEM cell

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

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

Course year: 3rd **Tutor(s)**: Andrea Lanzini, Massimo Santarelli

Academic context

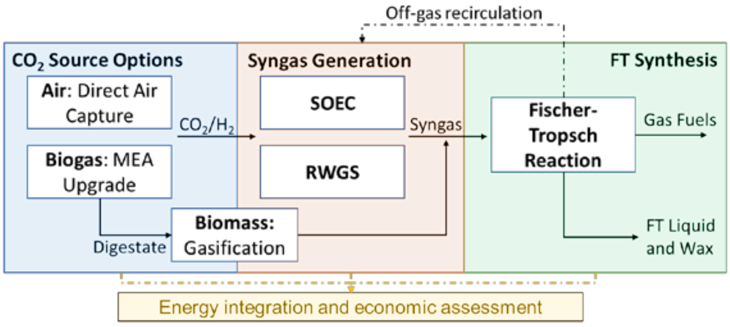
[1] Marchese, M., Giglio, E., Santarelli, M., Lanzini, A., "*Energy performance of Power-to-Liquid applications integrating biogas upgrading, reverse water gas shift, solid oxide electrolysis and Fischer-Tropsch technologies*". Energy Convers. Manag. X 100041, 2020.
[2] M. Marchese, N. Heikkinen, E. Giglio, A. Lanzini, J. Lehtonen, and M. Reinikainen, "*Kinetic Study Based on the Carbide Mechanism of a Co-Pt/γ-Al2O3 Fischer–Tropsch Catalyst Tested in a Laboratory-Scale Tubular Reactor*" Catalysts, vol. 9, no. 9, p. 717, Aug. 2019.
[3] 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, Finland (FI)
- Ineratec GmbH, Germany (D)
- Northwestern University, Illinois (US)

Highlights of the research activity

The PhD research activities are carried out within the framework of the European 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 (FT) products (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, describing the products distribution up to carbon number C_{80}. The model has been validated with a non-linear regression procedure on experimental results obtained in partnership with the project partner VTT. The kinetic model has been used in carbon utilization routes for power-to-liquid applications. The CO_2 is recovered from both biogas and air, and fed to either the RWGS reactor or a solid oxide electrolyer (SOEC) to generate syngas. Additionally, a gasification process was investigated. The resulting syngas is fed to a FT reactor whose behaviour is described by the described kinetic model. The aim of the process analysis 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. Optimal energy integration of each configuration plant was found. The best model configurations reaches a plant efficiency of 81.1% in the case of SOEC as syngas generator coupled with biogas CO_2 recovery, and 71.8% in the case of RWGS option, with a global carbon reduction potential of 79.4% and 81.7%, respectively. Moreover, extracting carbon dioxide directly from the air, 68.3% of the CO_2 enterering the system is removed and transformed into high moleacular weight FT hydrocarbons. With regard to the economic benefits of these routes, gasifing biomass reaches the lowest FT waxes production cost of 3.05 €/kg, alongside the upper bound of 7.3 €/kg using air-CO_2, against a marketl value of 2.5 €/kg fossil waxes.



CCU routes for the techno-economic analysis.

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

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

Course year: 3rd **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] Cococcetta, F.,Finesso, R.,Hardy, G.,Marello, O.,Spessa, E." Implementation and assessment of a model-based controller of torque and nitrogen oxide emissions in an 11 L heavy-duty diesel engine", Energies 2019,12(24),4704

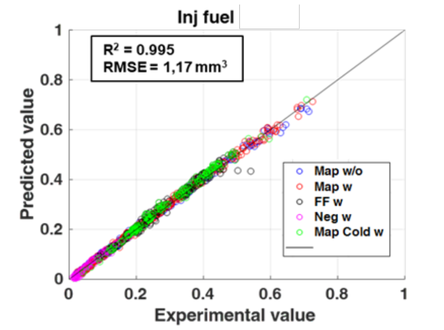
External collaborations

- 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 and could be useful to exploit the potential of real-time optimization techniques

The first activity performed in my PhD studies is the HERCULES project, carried out in collaboration with GM-GPS, in which a real-time model-based torque controller has been developed, with the aim to reduce the effort required for the torque-to-fuel maps calibration. The result of the project is a feed-forward ANN able to control the main injection quantity in order to achieve a torque target, also in engine modes that feature complex injection patterns. The ANN has been trained using a large virtual dataset (more than 200k points) generated by a previously developed and calibrated low-throughput mean-value physical combustion model that, due to its physical base, requires few points to be calibrated. The ANN has been validated along several transient tests including load ramps at different speeds and along RDE cycles, demonstrating a good accuracy in the fuel injection estimation. The computational time of the ANN was checked to be of the order of 30 microseconds on an ECU-like device, demonstrating real-time capabilities.



Accuracy in main injection quantity estimation of the ANN developed in the HERCULES project

Within the IMPERIUM H2020 EU project an innovative model-based combustion controller has been developed, which is capable of adjusting the main injection parameters (injection pressure, injection timing, injected fuel quantity), in order to achieve desired targets of torque and NOx emissions that come from an energy manager supervisor (EMS) in real time. The controller has been integrated in a wider control system and tested at the engine test bench and on a vehicle demonstrator (IVECO Stralis) along a high-road long-haul (Asti-Genova) mission.

At the end of the project the whole IMPERIUM system (including all the sub-functions developed by all the project partners) has been validated demonstrating its capability to reduce the vehicle fuel consumption and remaining compliant with pollutant emission regulations.

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

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

Course year: 3rd **Tutor(s)**: Massimo Santarelli, Andrea Lanzini

Academic context

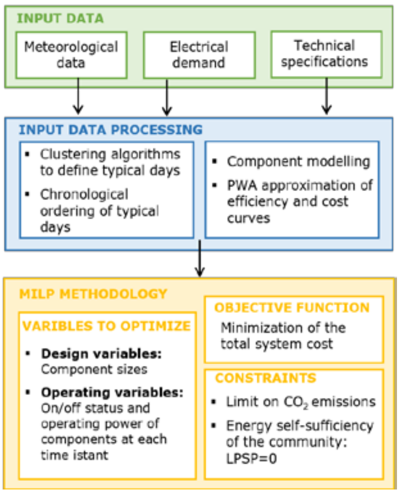
[1] P. Marocco et al., "A study of the techno-economic feasibility of H2-based energy storage systems in remote areas," Energy Convers. Manag., vol. 211, p. 112768, 2020.
[2] P. Marocco et al., "Online measurements of fluoride ions in proton exchange membrane water electrolysis through ion chromatography," J. Power Sources, vol. 483, p. 229179, 2021
[3] G. Buffo, P. Marocco, D. Ferrero, A. Lanzini, and M. Santarelli, "Power-to-X and power-to-power routes," Sol. Hydrog. Prod., pp. 529–557, 2019.

External collaborations

- SINTEF, Trondheim, Norway
- ENGIE Electro Power Systems (EPS), Rivoli, Italy
- Iren, Torino, Italy

Highlights of the research activity

My PhD research is mainly carried out in the framework of the EU H2020 REMOTE project, whose aim is to develop and test innovative hybrid (hydrogen + battery) energy storage solutions to support communities characterized by unreliable, or even missing, connections to the grid. Hydrogen can represent an interesting storage solution because of its high energy density, long-term storage capability and sustainability. However, research on H2-based components (i.e., electrolyzers and fuel cells) is required to further increase their performance, improve their lifetime and reduce their cost.
I first addressed my research at the component level with the aim of developing accurate models of electrolyzers and fuel cells and performing experimental tests necessary for the model validation. I then moved to the system level to study the entire off-grid P2P system taking advantage of results previously obtained from modelling and testing of the single components.
Concerning the experimental work, as a visiting research scientist at SINTEF, I performed experimental tests on PEM electrolyzers focusing, in particular, on the membrane chemical degradation. These tests were also useful to get experimental data for the validation of the PEM electrolyzer model I developed to be implemented within the P2P system model.
Moving to the system level, off-grid energy systems need to be correctly designed and operated in order to optimize the exploitation of local RES and make the community completely energy self-sufficient. I thus focused my research on the optimal design of such kind of systems by means of optimization algorithms: metaheuristic approaches (e.g., genetic and particle swarm optimization) and mixed integer linear program (MILP) methodologies. The single-layer (i.e., both optimal design and operation) MILP structure which I developed is shown in Figure 1. Time series aggregation techniques (clustering algorithms) are necessary to significantly reduce the computational time of the optimization process. The operating map of electrolyzer and fuel cell systems (derived from a detailed modelling of each component) is approximated by means of piece wise affine approximations to get reduced order models to be used in the MILP optimization framework. Moreover, the P2P system is operated so as to preserve as much as possible the state-of-health of batteries, electrolyzers and fuel cells. More in detail, wear costs of batteries and electrochemical devices (derived on the basis of the number of operating hours and start-ups they can withstand before replacement) were considered in terms of operating costs included within the objective function to be minimized (i.e., the total annual cost).



Single-layer MILP model

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

Topic: Improvement and development in multiscale 3D-1D tunnel fire modelling

Course year: 3rd **Tutor(s)**: Vittorio Verda, Elisa Guelpa

Academic context

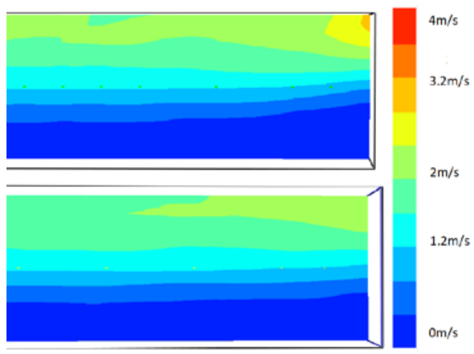
[1] F. Colella, G. Rein, V. Verda, R. Borchiellini, Multiscale modelling of transient flows from fire and ventilation in long tunnels, Computer & Fluids, 51:16-29, 2011.
[2] Cosentino S. et al. Integrating 1D and 3D modeling for the analysis of ventilation control in tunnels, ICHMT 2017, pages 2041-2060, 2017
[3] F. Colella, G. Rein, J. Torero, R. Borchiellini, A novel multiscale methodology for simulating tunnel ventilation flows during fires. Fire Technology, 2010.

External collaborations

- NIST (National Institute of Standards and Technology)

Highlights of the research activity

The risk of fire incidents in tunnels is proportional to the amount of tunnels and vehicles that are present in the roads. Year after year both of these numbers continues to increase, enhancing the risk of accidents inside tunnels, similar to some well known catastrophes of the last decades, like the Gotthard tunnel fire (2011), the Frejus tunnel fire (2005), among much others. The lessons learned from the incidents in the past have impulsed the research of Tunnel fires and, in this case, the CFD simulation of tunnels using a multiscale approach.
A big issue surrounding CFD tunnel simulations is the amount of time necessary to simulate long tunnels, as it might take days or weeks to simulate full 3D models. Our aim through Multiscale simulations in the last years is to develop a model capable of reducing the time expenditure by simplifying the zones far from the fire to a 1D model simulation.
In the last year the interaction with NIST (developers of the Fire Dynamics Simulator) has been closer, with the focus of improving the simulation capabilities of tunnels and obtaining a deeper understanding of how the model works for tunnels in general. For 5 months I transferred to their offices in Gaithersburg, Maryland, researching the stability of the tunnel fire simulations and the pressure solvers. As a result from the time spent there we made some verification case for the Verification guide of FDS, showing the capability of the FDS to replicate analytical results in the case of constant and linearly variable specific heat ratio.
Then at Politecnico, a series of test were conducted to determine the suitability of the different solvers to mitigate possible numerical oscillations in the code, and to establish good practices towards tunnel simulations. The results of this work are yet to be published.



Comparison of the open BC (upper) and the average BC (lower)

Still the main development in the last year has been the implementation of a modified boundary condition for the interaction between the 1D and 3D models. In FDS the only boundary capable to impose a pressure condition is an open boundary, imposing constant environmental conditions in the whole boundary section. Imposing constant conditions introduces perturbations and exit losses in the flow, which is not correct for a boundary internal to the tunnel, where the flow should continue unperturbed. To improve this pressure condition an average is found for the 5% of the tunnel before the boundary, to find the shape that the pressure distribution should have to fit the flow, then this distribution is normalized and multiplied by the value that the 1D has to exchange with the 3D. The result is a boundary that imposes a pressure value with an adequate pressure distribution and favors a steady flow and not a buoyant exit behavior, as seen in the figure.

First name: Antonino **LAST NAME**: MELI

Topic: Advanced Material application in Nuclear Fusion Reactor

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

Academic context

[1] Fundamental aspects of nuclear reactor fuel elements, Olander D.R, 1976
[2] Primary Radiation Damage in Materials, NEA/NSC/DOC (2015)9,
[3] A.Q. Kuang, N.M. Cao, A.J. Creely, C.A. Dennett, J. Hecla, B. LaBombard, R.A. Tinguely, E.A. Tolman, H. Hoffman, M. Major, J. Ruiz, D. Brunner, P. Grover, C. Laughman, B.N. Sorbom, and D.G. Whyte. Conceptual design study for heat exhaust management in the ARC fusion. Fusion Engineering and Design 137 (2018), 221-242, 2018.

Highlights of the research activity

The aim of my PhD is to investigate on the most performing alloys nowadays available to suit as structural materials for the wall of the nuclear fusion reactor, ARC, designed at the MIT. In order to reach such a goal, I want to study how the neutron irradiation affects the mechanical properties of candidate materials. The focus is on the effects of neutron flux coupled with both mechanical and thermal stresses can initiate damaging phenomena at the lattice level and eventually degradation of the material macroscopic scale.
At the beginning I read the state of art on the material science, with specific application in the nuclear industry: from the alloys implemented in the design of first nuclear reactors to the ones adopted in more recent reactors (for both fission and fusion application), to proper understand how, during the years, the alloys' performances have increased because of the research conducted on them (concerning neutronic irradiation damage resistance, and mechanical and thermal stresses resistance). After a while, I started to develop a model with the aid of the neutronic code OpenMC and the activation code FISPACT-II in order to study neutronic irradiation and induced activation effects on the materials of the wall components of the ARC fusion reactor.
Parallely I collaborated to develop a report on models concerning material damage prediction: it has outcome that depending on what we want to observe, some models might suit better than others. As a matter of fact, we concluded that, e.g., Molecular Dynamics (MD) gives a good prediction of the atoms motion in the lattice; Binary Collision Approximation (BCA) describes better how ions and recoils move in the matter; Density Functional Theory (DFT) works better for non interacting electrons. We have found also some codes implementing such models, as for LAMMPS for MD, SRIM/TRIM for BCA, and VASP or QuantumESPRESSO for DFT.

Material	Thickness [cm]	Neutron Flux [n/cm^2]	DPA/y	KERMA [kW/cm^3]	He Prod. [appm]
$YB_3C_5O_7$	3.40E-03	4.35743E+09 ± 2.96E+08	1.13E-04	1.09E-09	6.32E-03
CeO_2	2.79E-03	4.35576E+09± 2.84E+08	1.18E-04	1.22E-09	8.08E-03
MgO	3.40E-05	4.43963E+09 ± 2.81E+08	1.64E-04	8.73E-10	1.05E-02
Y_2O_3	6.80E-05	4.43915E+09 ± 2.81E+08	1.35E-04	8.27E-10	7.16E-03
Al_2O_3	5.10E-04	4.43552E+09± 2.80E+08	1.34E-04	9.12E-10	8.87E-03

During the summer I started to work on the neutronic irradiation and activation effects on high temperature superconductors (HTS), the REBCO, as for Rare Earth Barium-Copper-Oxygen tapes. These HTS are one of the key technologies of the ARC reactor because of their superior magnetic field confinment properties.
This work has been presented as a poster during the 31th Symposium of Fusion Technology - virtual edition (followed by paper submission in the late November). The aim of the study is to observe how REBCO behaves under neutron irradiation, considering the shielding effects of structural materials, such as the Inconel-718, Vanadium alloys, or even the ODS steels. So far, the results obtained for the Inconel-718 seem reasonable, at least matching with what suggests the literature. Specifically, the DPAs seem low, but, considering that the study is not finished yet, further validation and benchmark will be carried out using the calculation undergoing with the superPCs.

First name: Samuele **LAST NAME**: MESCHINI

Topic: ARC reactor safety assessment

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

Academic context

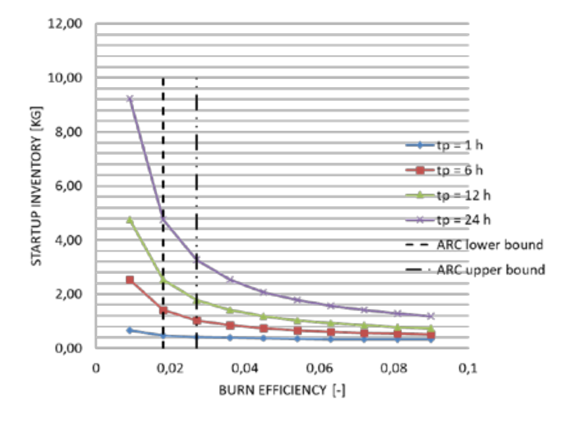
[1] B. N. Sorbom et al., “ARC: A compact, high-field, fusion nuclear science facility and demonstration power plant with demountable magnets,”Fusion Eng. Des., 100, 378, (2015),doi: 10.1016/j.fusengdes.2015.07.008.
[2] E. Zio, “Integrated deterministic and probabilistic safety assessment: concepts, challenges, research directions,”Nucl. Eng. Des., 280, 413, (2014).
[3] M. Zucchetti et al., “ARC reactor: radioactivity safety assessment and preliminary environmental impact study,”Accepted by Fusion Eng. Des., (2020), doi: https://doi.org/10.1016/j.fusengdes.2020.112132.

External collaborations

- ENI, DE R&D/MAFE – Magnetic Fusion Energy, San Donato Milanese (MI), Italy
- Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge (MA), USA

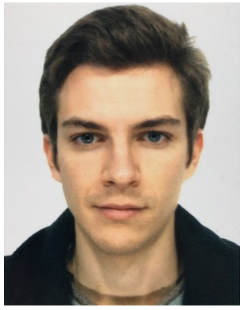
Highlights of the research activity

The first part of the research activity was devoted to an extensive literature review on the FLiBe molten salt and the tritium behavior in a fusion relevant environment. Specifically, FLiBe behavior in the ARC blanket was studied, as well as tritium diffusion and permeation in FLiBe and vacuum vessel structural materials (Inconel-718, V-Cr-Ti). Research results highlights the necessity of a detailed analysis of FLiBe flow in the tank by means of CFD simulation, to set the basis for a tritium transport model.
Since ARC is still in a conceptual design phase, design activities have been carried out in parallel with safety analysis. In doing so, the start-up inventory of the reactor was successfully estimated, and criticalities related to the burn efficiency, fuel cycle and tritium processing were highlighted. A possible solution relying on the direct internal recycling concept was proposed. Once the total inventory in the reactor was set, the analysis focused on two main components, the FLiBe tank and the tritium extractor. Three different extractors were analyzed and compared. Then, FLiBe and tritium inventories were estimated for the tank and for three different tritium extractors. A possible site for the construction of ARC was proposed, the most exposed individuals were identified and the impact of severe accidents involving the tank and the extractors was assessed. Results show that the early dose to the closest residents is well below regulatory limits. Radioactive dust production was investigated too; the related dose to the most exposed individuals is much higher than that associated to tritium releases.



ARC start-up inventory as a function of the burn efficiency. Lower and upper bounds for the burn efficiency are reported.

At system level, other accidental scenarios were analyzed. The energy released in the first wall by a disruption was quantified starting from the plasma design parameters. The following thermal transient was studied by solving numerically the heat conduction equation in the first wall. The thermal spike is still below tungsten melting temperature. Hence, bulk damages do not seem likely. However, thermal stresses and surface ablation may challenge the first wall. The effect of a Loss of Flow Accident on the vacuum vessel materials was analyzed as well. It is found that the low conductivity of FLiBe does not allow for an efficient cooling of the structural materials. The decay heat rises the temperature up to the failure of the structural materials, in a timescale of hours. Therefore, an emergency cooling system must be foreseen. Natural circulation of FLiBe can be exploited as well.



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

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

Course year: 2nd **Tutor(s)** Daniela Anna 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

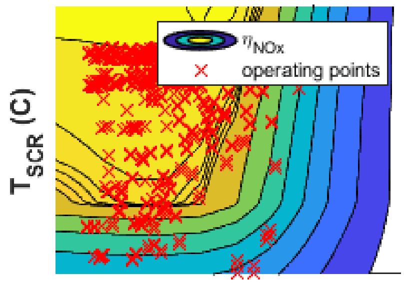
- FPT industrial
- IVECO
- ENI

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, with particular focus the SCR of a diesel-hybrid architecture.

The second year has been dedicated to two main aspects. Since the optimal design tool requires analyzing many simulations, simulation time is vital to the tool's impact on the industrial partner's research and development activities. Thus, numerical, programming and physical modelling aspects have been engineered to cut down simulation time while maintaining modelling accuracy. As a result, individual simulation time has been reduced by two orders of magnitude. The second main topic was assessing alternative methods for evaluating the impact of an ATS thermal management system on fuel consumption with a low-complexity model (which sacrifices prediction accuracy on NOx pollutants).



The SCR deNOx efficiency is mapped as a function of SCR temp and exhaust gases flow rate

First name: Alberto **LAST NAME**: MOSCATELLO

Topic: CFD simulations and experimental validation of industrial accidents and environmental pollution

Course year: 1st **Tutor(s)**: Andrea Carpignano

Academic context

[1] Vinnem, J.E. (2019). Offshore Risk Assessment vol 2. Springer
[2] Carpignano, A., T. Corti, A.C. Uggenti, and R. Gerboni, 2017, Modelling of a supersonic accidental release in Oil&Gas offshore: Characterisation of a source box, GEAM. Geoingengeria ambientale e mineraria, 58-64.
[3] Moscatello A. et al., 2020, "Scaling procedure for designing accidental gas release experiments", Engineering Computations.

External collaborations

- Ministero dello Sviluppo Economico (MiSE)
- École central de Lyon (Università di Lione)

Highlights of the research activity

The proposed research activity is part of a large project, founded by the Italian Ministry of Economic Development (MiSE) since 2015, named SEADOG (Safety and Environmental Analysis Division for Oil and Gas); it is also a diffused laboratory which aggregates five different departments of Politecnico di Torino: DENERG, DIMEAS, DIATI, DISAT and DISMA. Moreover, in June 2018, Politecnico di Torino and MiSE constituted the Competence Centre SEASTAR (Sustainable Energy Applied Sciences, Technology & Advanced Research) that represents a reference, also at international level, in the field of Oil & Gas safety, particularly offshore, and in the management of the transition towards a low carbon economy also for this kind of installations. The main objective of the research activity is a further development of the approach proposed in [1] based on the Computational Fluid Dynamics (CFD) in order to perform a more detailed simulation of the accidents that typically affect Major Hazard facilities like offshore platforms, nuclear plants, etc. This approach, called Source Box Accident Model (SBAM), aims at handling complex accidents in complex geometries with a reduced computational cost. The aim is to lay the basis for a safety driven design approach via CFD, which seems to be the better choice in order to reduce the risk associated to Major Accidents like the high-pressure gas releases in big congested environments (e.g. offshore platforms, nuclear plants). In this first year the CFD model was refined through some sensitivity analyses on the characteristic parameters, a numerical benchmark using a CFD standard simulation as a reference and a comparison with the standard CFD tools used in the industrial field (FLACS and KFX). SBAM was applied to different case studies concerning both flammable and toxic gases showing a good response in both cases. In these months, an experimental campaign is being carried out at the SEASTAR WT (wind tunnel) to validate SBAM. A scaled mockup of an offshore platform equipped with flow and gas sensors is employed to simulate an accidental high-pressure gas release of methane under wind conditions. To realize the experiments a rigorous scaling procedure was developed [2].
A first round of experiments showed a good agreement with the CFD results, however further investigations are needed to develop a correct measurements uncertainty quantification and a proper comparison method of the CFD and experimental values.

Scaled mockup of an offshore platform inside the test chamber of the SEASTAR WT.

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

Topic: Modeling liquid metals for nuclear applications

Course year: 3rd **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] G. F. Nallo, N. Abrate, S. Dulla, P. Ravetto, D. Valerio, "Neutronic benchmark of the FRENETIC code for the Multiphysics analysis of lead fast reactors", The European Physical Journal Plus 135:238 (2020), DOI: https://doi.org/10.1140/epjp/s13360-020-00171-8
[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

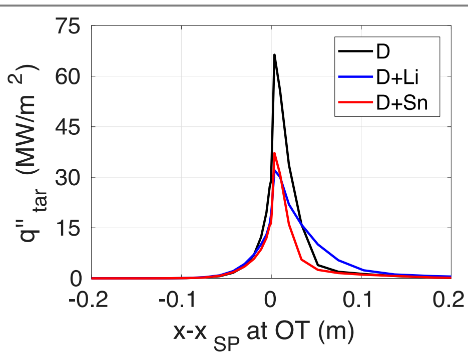
External collaborations

- Centro Ricerche ENEA Frascati, Italia
- Centro Ricerche ENEA Bologna, Italia
- Dutch Institute for Fundamental Energy Research (DIFFER), Eindhoven, The Netherlands

Highlights of the research activity

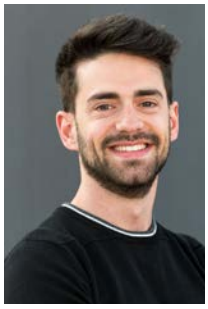
This Ph.D. research activity involved the multi-physics modeling of innovative components based on liquid metals (LMs) for both fusion and fission nuclear reactors.

The framework for the fusion-related part of the Ph.D. was represented by the LM divertor, which is one of the currently investigated alternative strategies to address the power exhaust problem in fusion reactors. This activity has been carried out in support of the preliminary design of an LM divertor for the EU DEMO reactor, currently ongoing within the EUROfusion consortium. The work consisted in performing edge plasma simulations, aimed at estimating the heat load associated to the plasma impinging on the divertor targets (see Figure 1), as well as the impact on the plasma itself of the metal (Li or Sn) eroded from the targets. To this purpose, a state-of-the-art tool for edge plasma simulations (the SOLPS-ITER code), self-consistently coupled to a model for the LM target erosion, has been applied for the first time to simulate the EU DEMO equipped with an LM divertor. During this 3rd year, the influence of purposely seeding Ar to reduce the target heat load was investigated. The results suggest that a promising operational window exists for an Sn divertor with Ar seeding.



Comparison of plasma heat flux profiles along the outboard divertor target (OT) with and without an LM divertor in place.

The framework for the fission-related part of the Ph.D. was instead represented by Generation IV Lead-cooled Fast Reactors (LFRs). The work consisted of two main tasks. First, the FRENETIC code for the multi-physics (neutronic + thermal-hydraulic) modeling of LFRs, previously developed at Polito, has been benchmarked against high-fidelity single-physics code (Serpent for Monte Carlo neutron transport and OpenFOAM for CFD) and applied to the simulation of the ALFRED reactor. Second, a new computational tool, based on the sub-channel method, for predicting the mass flow rate distribution and heat transfer in the gap between closed, hexagonal assemblies of ALFRED has been designed and implemented during this last year. Notably, the code development procedure had to comply to the state-of-the-art software quality assurance standards required by ENEA. This is mandatory, as the code will be applied in the design of ALFRED, which will then be submitted to the competent safety authority.



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

Topic: Decarbonization of Urban Areas: Electrical and Thermal energy integration

Course year: 2nd **Tutor(s)**: Marco Simonetti, Michel Noussan

Academic context

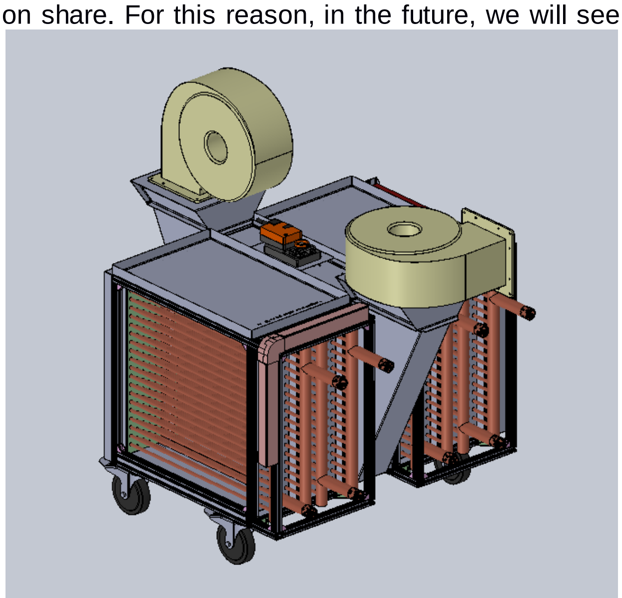
[1] Tu Y, Wang R, Zhang Y, Wang J. Progress and Expectation of Atmospheric Water Harvesting. Joule 2018; 2:1452–75. https://doi.org/10.1016/j.joule.2018.07.015.
[2] Connolly, D. (2017). Heat Roadmap Europe: Quantitative comparison between the electricity, heating and cooling sectors for different European 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

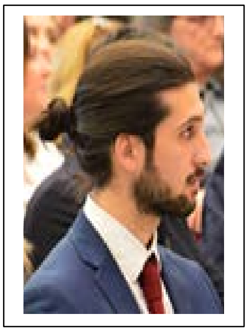
- Princeton University
- IEA Annex50 – Heat Pumps Technologies

Highlights of the research activity

Decarbonization of urban areas is driven by the electrification wave which is hitting especially the heating sector and the mobility one. On the other side, in some contexts electricity consumption is becoming an important issue as cooling systems are expected to put strong pressure on the electrical grid. These two phenomena together will require significant improvements in the electrical grid and the power generation sector to dramatically increase the low-carbon energy production share. For this reason, in the future, we will see cooperation more than a competition between full electrification and traditional technologies. As a PhD student, I am investigating the possible collaborations between the two sectors, quantifying the emission savings, the load flexibility, and the overall system efficiency. First, I had the opportunity to approach the project of an innovative geothermal district heating system exploiting the new future metro line in Turin as a thermal source for large heat pump system. Two solutions have been compared: a single low-temperature network with booster heat pumps, against a traditional high-temperature network. The low-temperature solution guarantees lower energy losses during the year, improving the overall energy efficiency (network + HP) and the possible multiple thermal source integration. On the other side, electricity consumption has increased, remarking the needs of clean electricity production. Another possible integration between thermal and electrical vectors relies on Adsorption machine which can be seen as cooling device and/or water harvesting machine. In the ReCognition EU project framework, we have designed a hybrid cooling machine able to use alternatively heat or electricity to produce cooling power. The prototype is based on an electrically driven heat pump and two silica gel coated heat exchangers. The first CFD simulation provides important improvement of the overall efficiency with respect to traditional chillers, reducing peak demand and improving the self-consumption of local renewable energy sources (thermal and/or electrical). Moreover, I am developing a dynamic simulator of the system which will be validated with the prototype. Atmospheric water generation purposes will be investigated too, with the aim of maximize the water collection instead of dehumidifies process air stream.



Hybrid Solar Cooling prototype 3D design



First name: Giuseppe **LAST NAME**: PINTO

Topic: Enhancing Energy Flexibility in Cluster of Buildings through Coordinated Energy Management

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

Academic context

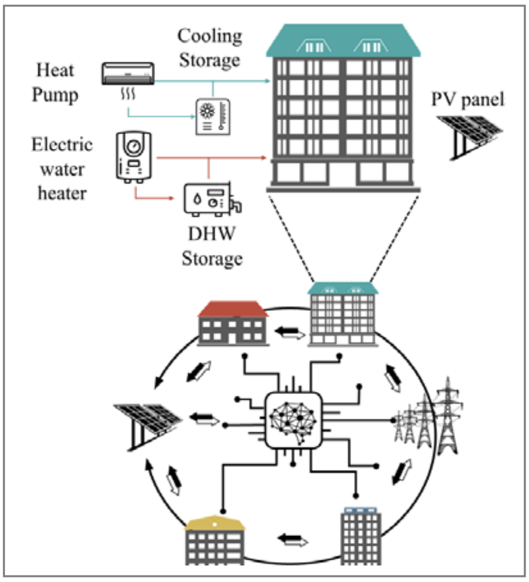
[1] Huang P., Fan C., Zhang X., Wang J. A hierarchical coordinated demand response control for buildings with improved performances at building group. *Elsevier, Applied Energy (2019)*.
[2] Hu M, Xiao F, Wang S. Neighborhood-level coordination and negotiation techniques for managing demand-side flexibility in residential microgrids. Renew Sustain Energy Rev 2021;135:110248.
[3] Vázquez-canteli JR, Nagy Z. Reinforcement learning for demand response : A review of algorithms and modeling techniques. Appl Energy 2019;235:1072–89.

External collaborations

- University of Texas at Austin
- University College of Dublin

Highlights of the research activity

Building energy management can enable energy flexibility by enhancing on-site renewable energy exploitation and storage operation, reducing energy costs and providing services to the grid (i.e., load shifting, peak shaving). However, when the energy management is faced shifting from a single building to a cluster of buildings, individual demand-side management may have negative effects on the grid reliability, like the peak “rebound” issue. Moreover, an uncoordinated management could cause undesirable new peaks or lead to suboptimal solution to the grid. The first period of the year was devoted to identify pros and cons of different ways of harmonizing the control of multiple buildings and the effects on computational costs and information requirements, in order to effectively perform a coupling with the optimal control technique avoiding computational burden and sub-optimal solutions. Particular attention was paid to the formulation of Reinforcement Learning (RL), an adaptive and potentially model-free control algorithm exploited in the research. RL agent directly learns an optimal control policy through a trial-and-error interaction with the environment. The main outcome of the first year was the development of a framework able to exploit a model-free Deep Reinforcement Learning (DRL) controller to coordinate the energy management of a cluster of buildings. The analysis has been performed developing a DRL controller to control the operation of thermal storages of a cluster of buildings providing benefits to both users and grid. The control problem analyzed involved renewable energy sources, variable electricity price and building coordination. To compare the DRL performances and underline the effect of a coordinate energy management versus a single building optimization, a manually optimized RBC controller baseline was introduced. Despite the complex environment, the DRL controller found an optimal control strategy, reducing cost (4%) and maximum peaks (12%). Moreover, the strength of such approach consists in not only the mere improvement of energy performances, but the opportunity provided by its adaptive nature to account the dynamic nature of the cluster environment. In fact, a large environment may involve rapid changes, such as consumption pattern modification and demand response programs. The research has shown how DRL controller was able to coordinate different buildings, increasing grid stability and energy efficiency of the systems.



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

Topic: Towards climate resilient nearly zero energy buildings; A comparative study on energy related components, adaptation strategies and whole building performance.

Course year: 2nd **Tutor(s)**: Vincenzo Corrado

Academic context

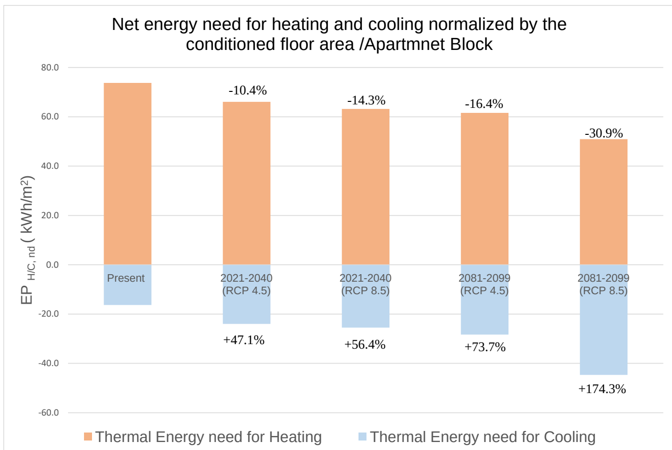
[1] Pérez-Andreu, Víctor, et al. "Impact of climate change on heating and cooling energy demand in a residential building in a Mediterranean climate." Energy 165 (2018): 63-74.
[2] Attia, Shady, and Camille Gobin. "Climate Change Effects on Belgian Households: A Case Study of a Nearly Zero Energy Building." Energies 13.20 (2020): 5357.
[3] 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.

External collaborations

- Institute of building research & innovation, Vienna, Austria (Operating agent of IEA EBC-Annex 80)
- Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA)

Highlights of the research activity

Climate change projections express that the climate pattern has been disrupted. One of the major problems caused by climate change is overheating of buildings, which leads to a significant rise in cooling energy consumption and energy shortage. Consequently, the main objective of the research is to investigate and optimize energy performance and thermal comfort of buildings in a changing climate.Following a deep review of literature during the first year, future weather data sets were developed using different methods, including regional climate model and time series adjustment. In the second year, the developed future weather data were used to analyze the impacts of climate change on Italian residential buildings' performance. The analysis was carried out for Milan, as it is one of the representative cities of the Italian middle climatic zone (2100 < *HDD* ≤ 3000), which includes 4250 Italian municipalities on a total amount of 8100. For different building types, the results clearly show that there is a drastic rise in cooling energy use and a moderate decrease in heating energy use, as expected (Fig.1). The overheating risk increases significantly as the warm discomfort hours raise between almost 30% to 155.3 %. Buildings with higher shape factor were found to be more sensitive to climate change, and the ones with a higher window to wall ratio experience more hours of warm discomfort. Besides, the effect of different scenarios on the Italian residential buildings is more severe in the long term. The climate change impact magnitude is not equal for different future weather scenarios and case studies, so that in a changing climate, it becomes necessary to perform a regional and localized analysis. The next step will be investigating the effects of climate change on nearly zero energy buildings (NZEB). Considering building stock large share of Europe's final energy consumption and CO_2 emissions, it is crucial to redefine the concept of nearly-zero energy buildings (NZEB) based on the changing condition. The study will be carried out by sensitivity analysis of the NZEBs requirements, under different scenarios using the variance-based model.



$EP_{H/C,nd}$ of an apartment block building-type under different scenarios in Milan

First name: Luca **LAST NAME**: PULVIRENTI

Topic: Exploiting V2X connections and advanced energy management strategies to achieve maximum CO_2 reductions from HEVs

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

Academic context

[1] Doulgeris, Stylianos & Dimaratos, Athanasios & Zacharof, Nikiforos & Toumasatos, Zisimos & Kolokotronis, D. & Samaras, Zissis. (2020). Real world fuel consumption prediction via a combined experimental and modeling technique. Science of The Total Environment. 734. 139254. 10.1016/j.scitotenv.2020.139254.

[2] Olin, P., Aggoune, K., Tang, L., Confer, K. et al., “Reducing Fuel Consumption by Using Information from Connected and Automated Vehicle Modules to Optimize Propulsion System Control,” SAE Technical Paper 2019-01-1213, 2019, doi:10.4271/2019-01-1213.

[3] Xu, B., Malmir, F., Rathod, D., and Filipi, Z., “Real-Time Reinforcement Learning Optimized Energy Management for a 48V Mild Hybrid Electric Vehicle,” SAE Technical Paper 2019-01-1208, 2019, doi:10.4271/2019-01-1208.

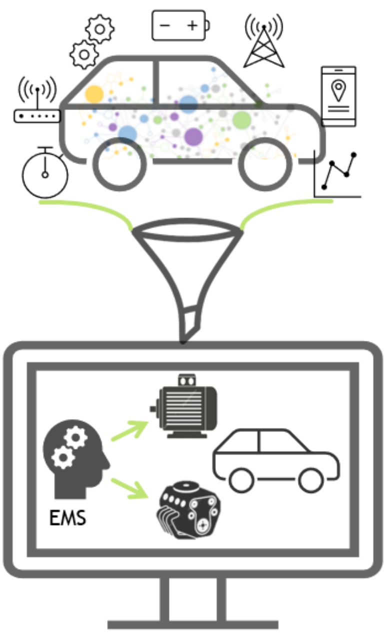
External collaborations

- FEV Italy
- Powertech Engineering
- Gamma Technologies LLC

Highlights of the research activity

Last-generation vehicles can be connected with the surrounding environment providing the chance to further improve fuel economy of Hybrid Electric Vehicles (HEVs). The aim of my research activity is to assess, through numerical simulation, the potentialities coming from the integration of Vehicle-to-Everything (V2X) information into the powertrain control strategy.

In order to fit my research activity into the research ‘map’ of the related field, I firstly carried out an extensive literary review to highlight the current state-of-the-art about Energy Management System (EMS) in hybrid powertrains. Moreover, during the first year of my PhD activity, I mainly focused on the investigation of the EMS of a real vehicle: state-of-the-art in terms of diesel HEVs available in the market. Thanks to a close collaboration with FEV Italy, which carried out an experimental campaign on the aforementioned vehicle, a P2 diesel PHEV, a huge amount of data was provided. The dependency of the EMS decisions on the main operating variables of the powertrain was found out thanks to the definition of a methodology for reverse engineering the strategy implemented in the EMS. The accuracy of the extracted strategy was later assessed through numerical simulation: the vehicle model featuring the extracted control strategy perfectly matched the experimental results also in real driving tests. The virtual test rig of the tested vehicle, built from the validation of the set of extracted rules against the experimental data, will be used to assess the potentialities of advanced energy management strategies in terms of CO_2 emissions reduction.



Methodology for reverse engineering the EMS of a HEV, starting from experimental data

First name: Antonio **LAST NAME**: RICCIO

Topic: Exhaust after treatment systems (EAS) modelling for off road diesel engines

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

Academic context

[1] Millo, F., Rafigh, M., Sapio, F., Barrientos, E. et al., "Application of Genetic Algorithm for the Calibration of the Kinetic Scheme of a Diesel Oxidation Catalyst Model," SAE Technical Paper 2018-01-1762, 2018
[2] Millo, F., Rafigh et al., "Application of a global kinetic model on an SCR coated on Filter (SCR-F) catalyst for automotive applications," FUEL, 2017
[3] Mallamo F., Longhi S., Millo F. et al., "Modeling of diesel oxidation catalysts for calibration and control purpose," International Journal of Engine Research, 2013

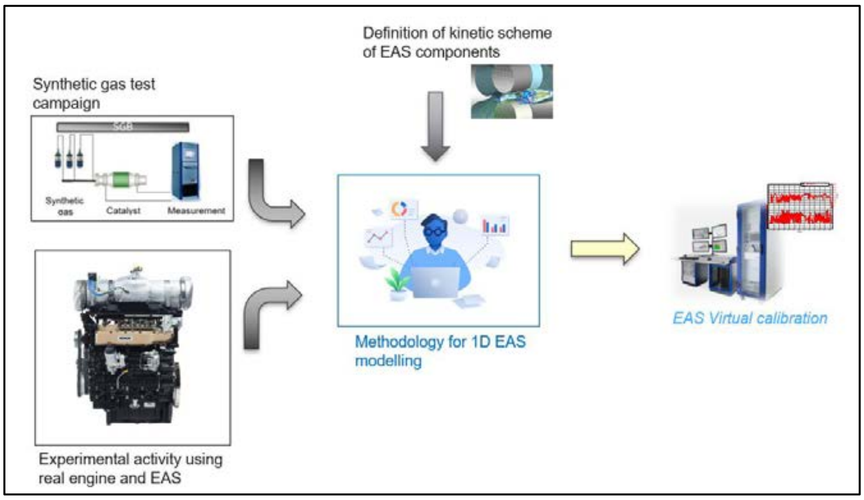
External collaborations

- Lombardini S.r.l, www.kohlerpower.com
- CNR - Istituto di Scienze e Tecnologie per l'Energia e la Mobilità Sostenibili (STEMS), www.stems.cnr.it
- AVL List GmbH, www.avl.com

Highlights of the research activity

The research activity is part of a wider research program carried out in Lombardini Srl, in close collaboration with Politecnico di Torino and CNR - STEMS, aiming to the development of advanced simulation methodologies to support the development of new technologies for the control of pollutant emissions from diesel engines for off-road applications.

In this first-year research work, different modelling approaches have been analyzed to create robust methodologies to predict the conversion efficiency of complex after-treatment systems. After an extensive literature review, an experimental campaign was carried out in a particular laboratory capable to test an Exhaust Aftertreatment System, or EAS, (constituted by three main components, a DOC, a DPF and a SCR) using synthetic gas flow was carried out. These data were then used to start a develop a one dimensional after-treatment system model. To do this, two different softwares have been used: AVL CruiseM (for the engine operating conditions and exhaust flow characterization) and GT-Suite(for the EAS modelling). Taking into account all the different operating conditions of an off-road diesel engine, this methodology allows to reduce the experimental effort for EAS calibration and management trying to meet all the expectations of an off road diesel engine's users: no impact on machine productivity, application flexibility, long service intervals, reliability, safety, compactness and fuel saving.



Development of a methodology to reduce experimental effort and enhance EAS virtual calibration using simulation tools

First name: Salvatore **LAST NAME**: ROGGIO

Topic: Study of Ultra-low NOx Diesel Combustion Systems by Synergetic Application of 3D-CFD and Single-Cylinder Engine

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

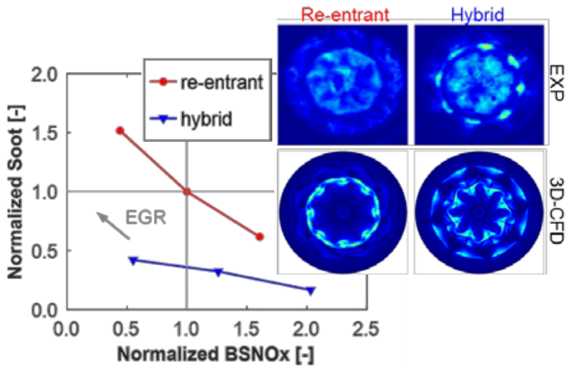
Academic context

[1] Eismark, J., Andersson, M., Christensen, M., Karlsson, A. et al., "Role of Piston Bowl Shape to Enhance Late-Cycle Soot Oxidation in Low-Swirl Diesel Combustion," *SAE Int. J. Engines* 12(3):233-249, 2019.
[2] Zha, K., Busch, S., Warey, A., Peterson, R. et al., "A Study of Piston Geometry Effects on Late-Stage Combustion in a Light-Duty Optical Diesel Engine Using Combustion Image Velocimetry," *SAE Int. J. Engines* 11(6):783-804, 2018.
[3] Belgiorno, G., Boscolo, A., Dileo, G., Numidi, F. et al., "Experimental Study of Additive-Manufacturing-Enabled Innovative Diesel Combustion Bowl Features for Achieving Ultra-Low Emissions and High Efficiency," SAE Technical Paper 2020-37-0003, 2020.

External collaborations

- PUNCH Torino S.p.A/ formerly General Motors Global Propulsion Systems
- Powertech Engineering Srl
- CMT-Motores Térmicos (Universitat Politècnica de València)

Highlights of the research activity



Left: Normalized soot-NOx trade-off; Right: experimental and 3D-CFD OH distribution. Partial load engine working point.

The research activity aims to develop a new low-emissions diesel combustion system by means a synergetic approach based on 3D-CFD numerical simulations and experimental tests. The first year of the PhD program was mainly focused on the numerical evaluation of different combustion systems to define the guidelines for a further optimization. For this scope, a predictive combustion model was built, featuring both a detailed chemical kinetic mechanism and a Particulate Mimic (PM) soot model. Firstly, a stepped-lip and a radial-bumps bowls for a swirl-supported light-duty diesel engine were investigated. These combustion systems have shown a noticeable improvement of the combustion process, reducing both the fuel consumption and the soot formation with respect to a conventional re-entrant bowl. Then, in order to evaluate the potential of a synergy between the abovementioned designs, a hybrid piston bowl was investigated. This innovative profile combines both a highly-reentrant sharp-stepped bowl and a number of radial bumps in the inner bowl rim equal to the injector nozzle holes. This innovative hybrid bowl highlighted a remarkable soot reduction compared to the conventional re-entrant bowl (up to -70%) without any thermal efficiency worsening. Finally, in the framework of a collaboration with CMT-Motores Térmicos, the numerical results were validated against the data coming from an optical access engine. The combustion image velocimetry and OH chemiluminescence experimental techniques were used to evaluate the kinematic analysis of the flame and to qualitative analyse the oxidation rate, respectively. The comparison between 3D-CFD results and experiments showed a very good match in terms of flame evolution and OH distribution. This analysis confirmed that the hybrid bowl design significantly reduces the flame-to-flame interaction with a consequent higher flame propagation toward the cylinder axis, resulting in better air/fuel mixing and thus faster combustion rate. Further analysis will be carried out on soot distribution, by synergetic application of 3D-CFD and optical access engine by means of 2-color pyrometry technique. The deeper understanding of the soot formation mechanisms will be crucial for the combustion system optimization.

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

Topic: Exergoeconomic Analysis and Optimization of Solid Waste Treatment Plants with the inclusion of Uncertainties

Course year: 3rd **Tutor**: Vittorio Verda

Academic context

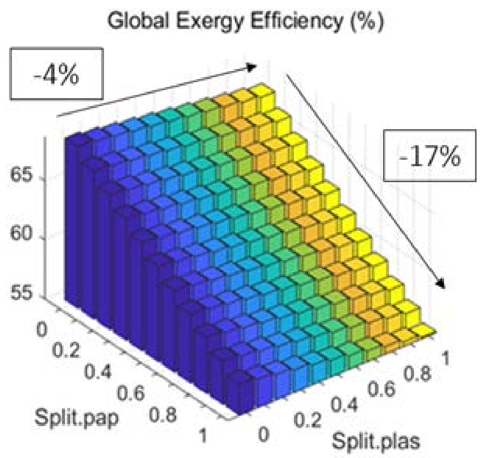
[1] Andreasi Bassi, S., Christensen, T. H., Damgaard, A. (2017). Environmental performance of household waste management in Europe – An example of 7 countries. Waste Management, 69, 545-557
[2] Z. Pourreza Movahed, M. Kabiri, S. Ranjbar, and F. Joda, "Multi-objective optimization of life cycle assessment of integrated waste management based on genetic algorithms: A case study of Tehran," *J. Clean. Prod.*, vol. 247, 2020.
[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 general objective of this research project is to use exergy criteria to assess the resource utilization into the SW treatment systems, according to the variety of scenarios that can occur. The development of an Integrated SWM system is strongly influenced by social, political and economic elements; in order to include the systemic uncertainties, stochastic tools are adopted for generating simulation scenarios. The instruments of Exergoeconomics are used since exergy is considered 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 paper and plastic recycling chains. The concept of Embodied Exergy (EE) was used to account for the avoided or additional exergy in different scenarios of SC. Exergy-based indicators were developed for comparing different recycling scenarios according to the SC of material streams. Moreover, a Multi-Objective Optimization (MOO) between the exergy efficiency and the total monetary cost was performed for seeking the best trade-off solutions; the optimization variables are linked to the amount of recycled materials. Results show that, even if the total recycling option is the best in matter of rational use of resources, trade-off solutions can be found for intermediate scenarios with moderate costs increment. 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 recycling. The production routes were established according to the 'grave to cradle' path (including polymerization, oil derivatives production and fossil fuel extraction) and the EE of the processes 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).



Trend of exergy efficiency with the plastic and paper selective collection degree

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

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

Course year: 2nd **Tutor(s)**: Romano Borchiellini, Carlo Cambini

Academic context

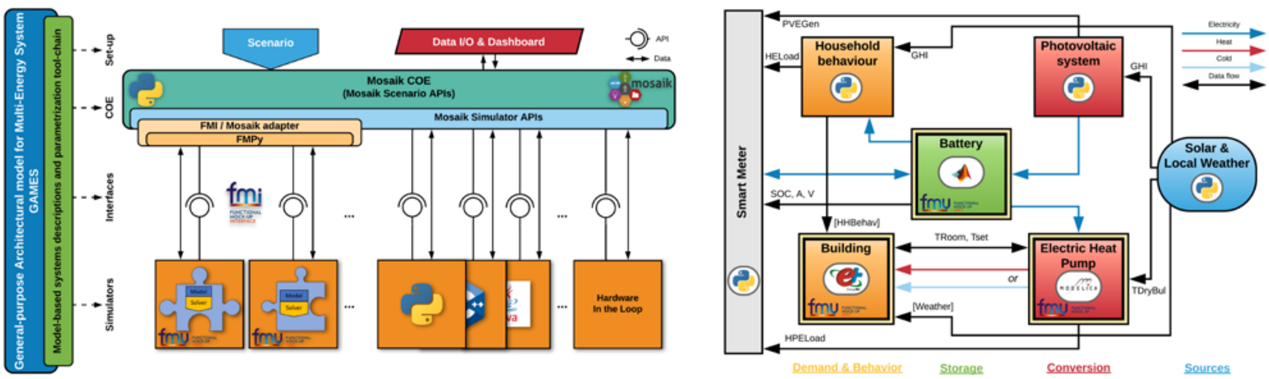
[1] D. S. Schiera, F. D. Minuto, L. Bottaccioli, R. Borchiellini, A. Lanzini, "*Analysis of Rooftop Photovoltaics Diffusion in Energy Community Buildings by a Novel GIS- and Agent-Based Modeling Co-Simulation Platform*," in IEEE Access, vol. 7, pp. 93404-93432, 2019, doi: 10/gf8pk3;
[2] D. S. Schiera, L. Barbierato, A. Lanzini, R. Borchiellini, E. Pons, E. F. Bompard, E. Patti, E. Macii, L. Bottaccioli, "A Distributed Platform for Multi-modelling Co-simulations of Smart Building Energy Behaviour," *in Proc. 2020 EEEIC / I&CPS Europe Conf.*, Madrid, Spain, 2020, pp. 1-6, doi: 10/gg68pt;
[3] L. Barbierato, D. S. Schiera, E. Patti, E. Macii, E. Pons, E. F. Bompard, A. Lanzini, R. Borchiellini, L. Bottaccioli, "GAMES: A General-Purpose Architectural Model for Multi-energy System Engineering Applications," *in Proc. 2020 COMPSAC Conf.*, Madrid, Spain, 2020, pp. 1405-1410, doi: 10/ghj97f.

External collaborations

- European Project H2020 PLANET

Highlights of the research activity

During the second year of PhD, the proposed platform for the analysis, simulation, and optimization of **Urban Energy Systems** (UES) at different level of abstraction and spatiotemporal frames was further developed.
The platform adopts a **Model-Based Engineering** (MBE) approach defining an extension of the well-known Smart Grid Architecture Model (SGAM) called **GAMES** (General purpose Architecture for Multi-Energy System) [3], and a **hybrid multi-modeling co-simulation infrastructure** that can integrate sub-models coming from different domain-specific modeling tools and modeling paradigms (Fig. 1-*left*).
GAMES aims at adding more functionalities to SGAM, i.e., description and integration of other energy networks with electricity grid, integration of analysis and simulation tools through a multi-modeling co-simulation infrastructure, composition and automation of use cases and scenarios throughout the MBE process. The software implementation exploits the **co-simulation framework** and implements the **Functional Mock-up Interface** (FMI) standard to couple and synchronize heterogeneous simulators and models. A first **case study** was formalized to look inside a **single building energy system** and model the internal parts and components using simulators and connect them through co-simulation techniques. Buildings are responsible of large consumption of energy in our cities, and they represent the **smallest primary entity of UES**. Then, we will scale the simulation up to the district level, integrating the **dynamic behavior of the energy networks**.
A first demonstration example of the case study was developed and simulated to evaluate energy performance in smart buildings [2] (Fig. 1-*right*).



(*left*) Co-simulation infrastructure. (*right*) Simulators block diagram of the building case study.

First name: Sonja **LAST NAME**: SECHI

Topic: Multi-scale energy and materials modelling for the decarbonisation and sustainability of the industrial sector

Course year: 1st **Tutor**: Pierluigi Leone

Academic context

[1] Tobias Fleiter, Matthias Rehfeldt, Andrea Herbst, Rainer Elsland, Anna-Lena Klingler, Pia Manz, Stefan Eidelloth, "A methodology for bottom-up modelling of energy transitions in the industry sector: The FORECAST model", *Energy Strategy Reviews*, Volume 22, 2018, Pages 237-254,
[2] Stefan Pfenninger, Adam Hawkes, James Keirstead, "Energy systems modeling for twenty-first century energy challenges", *Renewable and Sustainable Energy Reviews*, Volume 33, 2014, Pages 74-86
[3] Joris Proost, "Critical assessment of the production scale required for fossil parity of green electrolytic hydrogen", *International Journal of Hydrogen Energy*, Volume 45, Issue 35, 2020, Pages 17067-17075

External collaborations

- Engie
- Italgas
- Enea

Highlights of the research activity

The preliminary phase of the research activity was devoted to a general review of the structure and features of the most relevant global and regional energy models with a focus on the modelling of the industry sectors with the aim to identify the best tools available today possibly open source.
Considering the review carried out and the availability of external institutions for collaborations, one of these models has been selected for the next phase of the study that will include the modeling of a region with a focus on the industry sector. Moreover, this first part of the study included the comparison of the results obtained in different scenarios from the most important global energy models (ETP, WEM, PRIMES, NEMS) with an attempt to homogenize and use them for the improvement of the methodology of tecno-economic feasibility studies of single industrial plants carried out together with Engie B2B. In parallel, a second activity of the research involved the study and the collection of data (hourly electricity and fuel profiles, process technologies and energy technologies) of some selected industrial sectors with a particular attention to the food sector in several countries in different regions of the world (USA, Central America and Europa). Among the decarbonization options, the first objective of this part of the research concerned the substitution of the fossil fuel used in the plants with the exploitation of waste produced within the plants (e.g. bagasse, vinasse, fruits, etc) and the production of electricity thanks to combined energy systems of other renewable energy sources like solar and wind technologies. A complete technological scouting with a 2050 horizon on both the process (eg. New CIP system, solar distillation) and the energy production has been started and will complete this phase of the study.
A third activity of the research is about the use of hydrogen in European industrial sectors in order to assess the potential of green gases not only for energy use but also for the process of refineries products, chemicals and other products in in manufacturing process. The work done so far is concerning the collection of data and the study of specific industrial process in order to assess the material and the energy flows included in the system object of the study and potential synergies between processes.

Technological scouting for food sector – focus on spirit sector

Fuels: decarbonising fuel supplies	Technology	End-Use Technology		
Biogas production from waste	Anaerobic Digestion (AD)	Biogas/green fuel boiler	Fuel Cell: CHP configuration	Biogas Engine CHP: configuration
Biomethane production from waste	AD+biogas upgrading			
Biomethane syntesis from waste + CO2 reuse (process)	AD+biogas upgrading+CO2 recirculation			
Hydrogen Production from RES	Electrolysis (Alkaline, PEM, SOEC)			

Energy Carriers	Technology
Electricity from PV	PV panels with high efficiency
Electricity from wind	Turbine - commericial size
Electricity from hybrid grid (PV+wind)	PV+commericial wind turbines
Thermal Energy/steam from solar collector	Solar collectors / Solar Distillation
Thermal Energy/steam from CSP	Concentrated Solar Power

Process	Technology
Clean in Place (CIP) and cleaning without steam	Chemical cleaning without the application of heat, ultrasonic CIP (small scale)

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

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

Course year: 2nd **Tutor(s)**: Massimo Zucchetti; Raffaella Testoni

Academic context

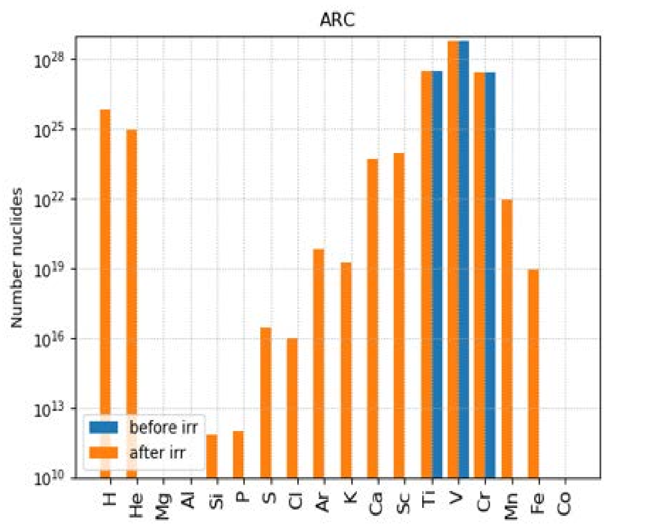
[1] Sorbom, B. N., et al. "ARC: a compact, high-field, fusion nuclear science facility and demonstration power plant with demountable magnets." Fusion Engineering and Design 100 (2015): 378-405.
[2] Segantin, S., et al. "Neutronic comparison of liquid breeders for ARC-like reactor blankets." Fusion Engineering and Design 160 (2020): 112013.
[3] Segantin, S., et al. "ARC reactor–Neutron irradiation analysis." Fusion Engineering and Design 159 (2020): 111792.

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 the analysis and evaluation of suitable materials for the core 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 neutronic studies on both the liquid blanket and the vacuum vessel structure have been carried out taking advantage of numerical methods and simulation software.
Tritium breeding ratio of several lithium-based compounds has been evaluated with the help of Monte Carlo neutron transport simulation tools. The study was a detailed assessment on tritium breeding ratio of different compounds, a parametric study on lithium-6 enrichment and a neutron induced activation analysis. Results of the study confirmed that the best choice for the blanket should be the FLiBe ($2LiF$-BeF_2) molten salt, already set as baseline compound, but also highlighted LiFNaFZrF4 as possible backup in case the application of beryllium turns out to be commercially unsustainable.
The analysis then focused on the irradiation damage on the structural material of the vacuum vessel, in the case of a low activation component design (V-4Cr-4Ti). Results showed a substantial difference in damaging mechanisms between a fusion reactor like ARC and canonical fission reactors. Nuclear reactions are mainly dominated by (n, 2n), (n, p), (n, α) reactions. Transmutation mainly goes in lighter elements direction (see figure) and it is not expected to be the damaging mechanism of main concern. Main forms of damage have been identified to be Frenkel pair clusters and hydrogen and helium transmutation. Combined they increase the swelling rate, which has been identified as the most likely material weakening mechanism.



V-4Cr-4Ti transmutation after 1 full power year in ARC vessel irradiation conditions.

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: 4th **Tutor(s)**: Massimo Santarelli, Ignasi Casanova

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

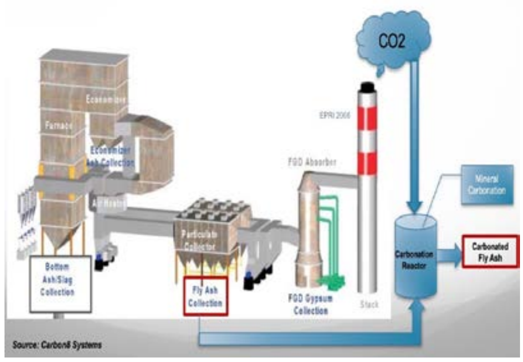
- Universitat Politecnica de Catalunya (UPC), Barcelona Tech., Spain
- NETL Institute for the Design of Advanced Energy Systems, Pittsburg (PA, US)
- University of California, Los Angeles (CA, US)

Highlights of the research activity

The research is centered on the new opportunities related to CCUS (carbon capture, utilization and storage) processes, useful at the level of mitigation of the climate change, but also able to open new business opportunities in the technological arena. The analysis is developed at two levels: (a) technical analysis of different pathways of CCUS; (b) analysis of the pathways for commercialization (and related barriers) of carbon-based products. The analysis consists of a two-pronged approach. First, the techno-economic modeling of selected CCUS processes, by the development of mathematical models dealing with the technological mechanisms and concentrating on the techno-economic analysis procedures. Second, assimilate the affairs associated with commercializing carbon-based products by understanding the enablers and barriers that affect this procedure. In this context, the work focuses on two major CCUS pathways:

- production of synthetic fuels (gas as synthetic methane; liquid as synthetic methanol)
- mineral carbonation of fly ashes, to be used in the concrete industry

The pathway of synthetic fuels has been modeled in their technical and economic aspects, in order to analyse the technical barrier and the final cost of the products. The pathways have considered both a synthetic fuel in gas form (lower energy density, easy distribution, market opportunities in the stationary and transportation sectors) and in liquid form (higher energy density, market opportunity as fuel but especially as chemical precursor). The pathway of mineral carbonation analyses the reaction between the CO_2 contained in the flue gas and high-calcium fly ash, two underutilized wastes formed at coal power plants. The aim is to manufacture carbonated fly ash, a commodity that can permanently capture CO_2 with the benefit to be a complementary cementitious material used in the construction industry. The identification of business opportunities for carbon-based products, yielding an attractive ROI, employs a qualitative study methodology analyzing the barriers to technology commercialization of CCUS especially in the concrete/construction industry.



Process flow diagram for mineral carbonation

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

Topic: Smart energy solutions for sustainable cities and policies

Course year: 2nd **Tutor(s)**: Guglielmina Mutani, Marco Masoero

Academic context

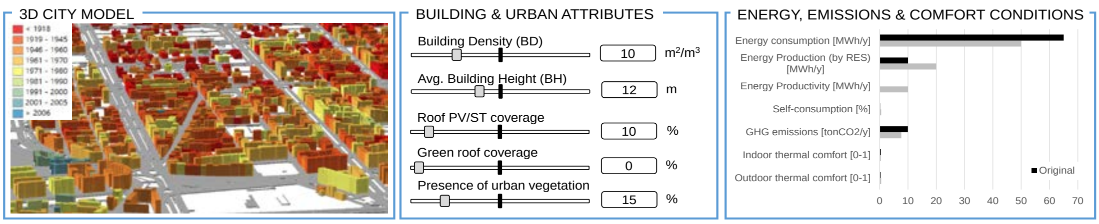
[1] "Building energy modeling at neighborhood scale", G. Mutani, V. Todeschi, in: *Energy Efficiency* (2020) DOI: 10.1007/s12053-020-09882-4
[2] "Energy consumption models at urban scale to measure energy resilience", G. Mutani, V. Todeschi, S. Beltramino, in: *Sustainability*, Vol. 12, No. 14, 5678 (2020) DOI: 10.3390/su12145678
[3] "Smart solutions for sustainable cities. The Re-Coding experience for harnessing the potential of urban rooftops", V. Todeschi, G. Mutani, L. Baima M. Nigra, M. Robiglio, in: *Applied Sciences*, Vol. 10(20), 7112 (2020) DOI:10.3390/app10207112

External collaborations

- Ecole Polytechnique Fédérale de Lausanne (EPFL), CH
- Idiap Research Institute, Martigny, CH
- Joint Research Centre (JRC), Ispra (VA), IT

Highlights of the research activity

The civil sector is the most important energy consumer in the EU: 97% of the EU building stock is not energy efficient and only 0.2% of residential buildings in the EU are undergoing significant retrofit interventions.
The development of Urban-Scale Energy Models (USEM) is currently the goal of many research groups due to increased interest in evaluating the impacts of energy efficiency measures in cities. These models are useful in order to explore energy consumption, emissions distribution and thermal comfort conditions at district scale, and also in order to quantitatively assess retrofit strategies and energy supply options. Since building geometry, urban morphology and local climate are all crucial to the optimization of the energy performance of buildings, USEMs make it possible to obtain lower energy demand by improving the morphology of the built environment. The novelty of this kind of modelling is that it adds a number of variables to the energy balance of the built environment in order to take the urban context into account: examples include (i) thermal radiation lost to the sky of the built environment (quantified through the use of the sky view factor), (ii) solar exposition (described considering information pertaining to the main orientation of the streets and the relative height of the district with respect to its surroundings), (iii) the urban canyon height-to-distance ratio that quantifies the hourly incident solar irradiance [1]. Up to now, USEMs have considered few variables that influence consumptions, especially as regards the urban context.
During my PhD research activities, USEMs based on a dynamic-energy balance of buildings at urban scale have been designed, calibrated, optimized and validated [2]. A sensitivity analysis has been carried out in order to identify the variables that most influence the heating consumption in different urban contexts. Through the application of these USEMs, a variety of issues have been investigated: (i) How can USEMs be applied to a larger building stock with high accuracy and low simulation times? (ii) How can the energy performance and energy productivity of a building be improved by taking into account the building's shape and the urban morphology? (iii) What retrofit interventions can be carried out while adhering to the building codes and the environmental regulations and how they can be promoted using incentives and financial schemes? [3]
The main application of the research is to create a platform to help stakeholders, urban planners and policy makers to plan sustainable cities and smart energy systems, while ensuring energy security, affordability and environmental sustainability for more resilient cities (Figure 1).



Example of urban-scale energy tool for the city of Turin

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

Topic: The Integrated Rural Renewable and Sustainable Energy Planning (IR^{2}SEP) Framework for Low-Income Countries: A Nigerian case study.

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

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

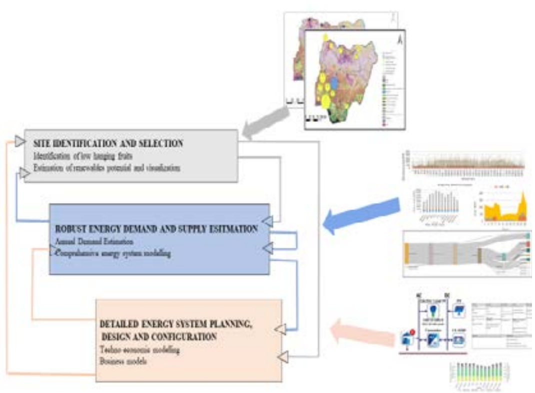
Highlights of the research activity

This research primarily presents and illustrates an integrated rural renewable and sustainable energy planning (IR^{2}SEP) framework for low-income countries. This framework provides a unified road map for energy planning, system design, and operation with renewable energy integration geared towards improving localized energy access in rural areas. 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 low-income countries with focus on rural communities in order 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 action steps from 1) site identification and selection through 2) robust energy demand and supply estimation 3) detailed energy system configuration.

This IR^{2}SEP framework is self-reinforcing, very adaptable and rgeneralizable. It allows for bi-directional flow of information between the different action steps such that attests to the interoperability, and interconnectedness of the different approaches and models utilized. It therefore exudes versatility and flexibility for implementation with existing tools and futuristic tools. The application of this strategy is such that can support the adoption of case studies applications at varying scopes; for instance, it could go from an aggregated country wide scope to more disaggregated scope considering the availability of data. This buttresses the originality of this strategy. In conclusion, the strategy is poised to completely change the narrative of rural areas and can be regarded as a proverbial "springboard" to spur sustainable development in rural areas of low-income countries. It could also standardise rural energy planning and set the precedence for future energy access endeavours.

IR^{2}SEP Framework



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

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

Course year: 2nd **Tutor(s)**: Sandra Dulla, Roberto Bonifetto

Academic context

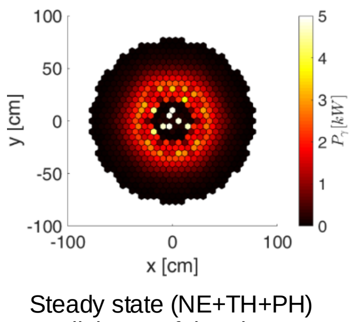
[1] R. Bonifetto, M. Utili, D. Valerio, and R. Zanino, “Conceptual design of a PAV-based tritium extractor for the WCLL breeding blanket of the EU DEMO : effects of surface-limited vs . diffusion-limited modeling,” submitted to *Fusion Eng. Des.*
[2] F. Papa *et al.*, “Engineering design of a Permeator Against Vacuum mock-up with niobium membrane.”,submitted to *Fusion Eng. Des*
[3] D. Valerio, S. Dulla, G. F. Nallo, and P. Ravetto, “Coupled Modelling of the EBR-II SHRT-45R Including Photon Heat Deposition,” *Proc. PHYSOR 2020, Cambridge, United Kingdom*, 2020.

External collaborations

- ENEA
- CIEMAT
- EUROfusion

Highlights of the research activity

The research activities foreseen in the PhD project address the multi-physics modeling of liquid metals in both fusion and fission nuclear systems. In particular, the work on the fusion topic is related to the Tritium Extraction and Removal Systems (TERS) in the fuel cycle of the EU DEMO reactor, whereas for the fission field the focus is on the further development and application of the FRENETIC code to the analyses of Liquid Metal Fast Breeder Reactors (LMBRs).The fusion activities were concentrated on the Permeator Against Vacuum (PAV) technology for the large-scale TERS of the EU DEMO reactor [1]. The task was to design the PAV to get the desired efficiency of tritium extraction. The Nb was selected for the membrane (i.e., the pipes in which the liquid PbLi with dissolved tritium flows) for its permeation properties. The assessment was carried out by a new permeation model where phenomena on the membrane surface are also accounted for, besides the pure diffusion across the membrane bulk already included in the existing diffusion-limited model used son far. This new model is based on the theory of Pick and Sonnenberg, but the source term has been modified to include the turbulence phenomena (and relative mass transport) of the liquid metal flow in which the isotope is dissolved, together with recombination and dissociation mechanisms on both sides of the membrane. To conclude the activities related to the TERS, a conceptual design of the P&I has been proposed, foreseeing different operational conditions (including few off-normal transients).The new surface model was also applied to the design of the mock-up which is going to be tested at ENEA Brasimone in the TRIEX-II facility, at the beginning of 2021 [2]. The TERS conceptual design and the mock-up engineering design have been both presented at the SOFT2020 Conference (virtual edition). The fission activities were focused on the modelling of photon heat deposition within the FRENETIC code. The aim of the study was to validate its photon diffusion module, using as case study the experimental data of the SHRT-45R test of the EBR-II sodium-cooled reactor, which was part of an international benchmark proposed by IAEA on an unprotected loss-of-flow-accident. In fact, the EBR-II was heavy loaded with stainless steel fuel assemblies. To generate the attenuation coefficients, neutron and photon KERMA, and production cross sections for the diffusion of photon rays, a model of the EBR-II in the Monte Carlo code Serpent 2 was developed. Firstly, a pure neutronic steady state calculation was performed by the FRENETIC code to show the relative fraction of photon heat deposition (See Figure 1). Secondly, coupled calculations were performed in steady-state conditions. A comparison between simulation with and without the photon deposition was performed and, and the results were presented at the PHYSOR2020 Conference.[3]



Steady state (NE+TH+PH) radial map of the photon power integrated per FA.

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

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

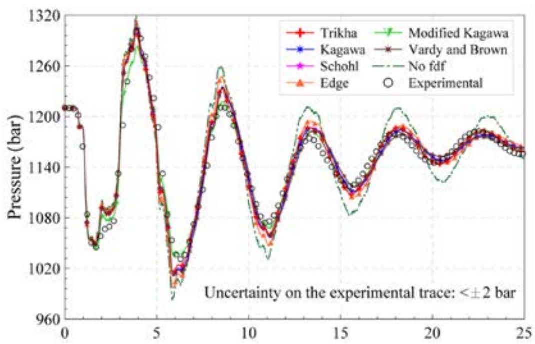
Course year: 3rd **Tutor(s)**: Alessandro Ferrari, Antonio Mittica

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, O. Vento, Influence of frequency-dependent friction modeling flows in high-pressure flow pipelines, Journal of Fluid Engineering, Volume 142, August 2020.
[3] A. Corvaglia, A. Ferrari, M. Rundo, O. Vento, Three-dimensional model of an external gear pump with an experimental evaluation of the flow ripple, Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, April 2020.

Highlights of the research activity

In this three 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. The hydraulic characterization of the injection system has been performed with and without 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, when the new control was used. Also for Pilot-Main injection, an improvement for all the dwell time range was appreciated, especially in the digital and continuous rate shaping regimes: in this case the error can pass from 10 mg to 2 mg. A different approach, based on the time frequency analysis (TFA), has also been developed to obtain the feedback signal for the control of the injected mass, through a TFA "virtual needle lift sensor" that is able to detect the injection temporal length (ITL). This can be used to predict the injected mass by using the nominal pressure-ITL correlation, that is independent of the fuel temperature. A further activity concerning the fuel temperature effect on the injector performance has been done, where a 1D numerical model has been validated and used to investigate the behavior of the injector dynamic, in terms of needle lift, pressure in the control chamber and pressure in the delivery chamber.



Numerical pressure traces for different FDF methods

I also performed an analysis on frequency-dependent friction (FDF) models in the high-pressure circuit of a Common Rail system. The main objective of this work was 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 compared the results of the various methods by using home-made and commercial numerical tools. It has been seen that the frequency-dependent friction is not determinant if the numerical simulation uses two pressure signals as boundary conditions. Viceversa, if a 1D injection system model is used where the boundary conditions are a rail pressure signal and the current to the solenoid valve, the frequency-dependent friction helps to improve the results of numerical simulations, whatever the method used to consider it (therefore, the simplest one can be selected). This results can be applied for pipes with a shorter aspect ratio than 800 and lower Reynolds number than 10^4.

I also focused my research activity on the polytropic approch to model compressible viscous diabatic flows. A new set of analytical formulas have been proposed and the distributions have been compared with those of the classic Fanno flow. Limits of the polytropic approach have been studied by means of a numerical model where a variable polytropic coefficient is used.

A final activity that I have followed concerned the analysis of the flow-rate ripple detected in an external gear pump. A 3D model of the pump has been prepared and the numerical results have been compared with the flow-rate measured by means of the Flotec device, an innovative flow-meter patented at the Politecnico di Torino and used to measure high-pressure flow-rates.

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: 2nd **Tutor(s)**: Roberto Finesso, Stefano Malan and Stefano d'Ambrosio.

Academic context

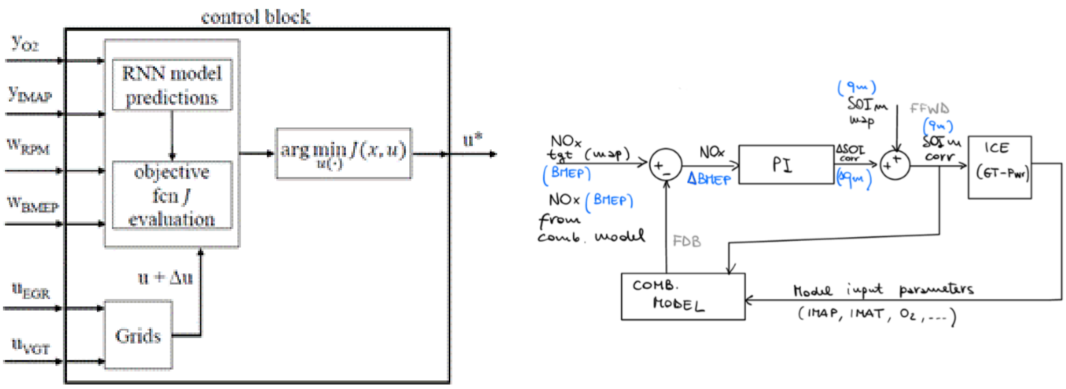
[1] Malan, S. A., Ventura, L. (2020) A Systematic procedure for engine air-path procedure, In: International Journal of Mechanics and Control, JoMaC, Vol. 21, No. 01, pp. 127-138, 2020.
[2] Ventura, L. and Malan, S., "Intake O2 Concentration Estimation in a Turbocharged Diesel Engine through NOE," SAE Technical Paper 2020-24-0002, 2020, https://doi.org/10.4271/2020-24-0002.
[3] Ventura, Loris; Malan, Stefano A (2020) NLQR-Iteration control of High Pressure EGR in Diesel Engine, ICCAS 2020, 13-16 Oct. 2020.

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. In the second year the knowledge gained during the previous year led to the development of an airpath controller for a 2.3L FPT diesel engine. The development of the controller was carried out based on 4 activities, which are described hereafter:

1. Investigation of different input signals for system identification procedure (user defined ramps, ASCMO, etc…).
2. Identification of neural networks to be embedded in the control algorithm.
3. Design of NLQR air path control system that handles the intake O_2 concentration and the boost pressure.
4. Testing of the developed control system through Model-in-the-Loop procedure.

After the development of the air path control system, a cycle-to-cycle combustion controller for the management of engine torque and NOx has been developed. Each cylinder is managed individually by its own control loops (Torque and NOx).



a) b)

a) NLQR air path control architecture. B) Closed loop combustion controller architecture.

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

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

Course year: 2nd **Tutor(s):** Stefano Corgnati, Giulio Mondini

Academic context

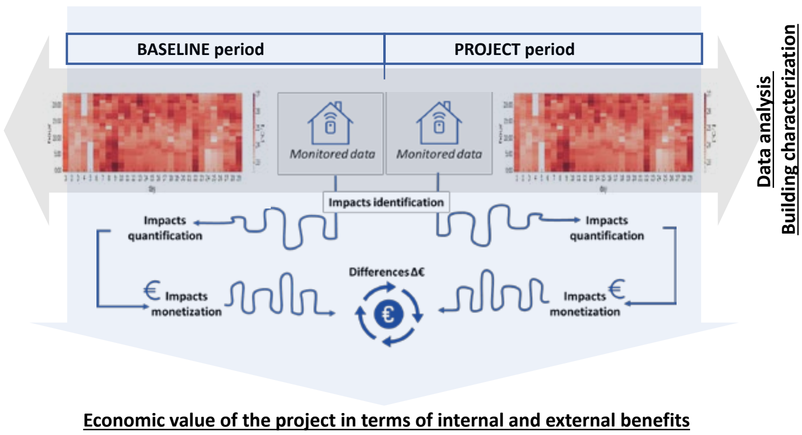
[1] Fisk W. J., Black D., Brunner G. (2011). *Benefits and costs of improved IEQ in U.S. offices*. Indoor Air 21: 357-367.
[2] IEA (International Energy Agency), EBC (Energy in Buildings and Communities Programme), *Statistical Analysis and prediction methods*, Annex 53, Volume V, 2013. ISBN: 978-4-9907425-6-0.
[3] Becchio C., Bottero M., Corgnati S. P., Dell'Anna F., Delmastro C., Pesce E., Vergerio G., *A Cost Benefit Analysis based model to evaluate the retrofit of a reference district*. Building Simulation 2019 - Rome, 2-4 September 2019.

External collaborations

- H2020 Mobistyle project consortium
- Enel Foundation
- Compagnia di San Paolo

Highlights of the research activity

Cities are considered as main actors towards a future sustainable society. Among others, analysing the role of the built stock in the energy transition in terms of its (physical and not-physical) retrofit potential is a key research activity, which requries to priorply characterize and model buildings behaviour. In dealing with this topics, the role that buildings have in guaranteeing comfort and welling to the occupants should not be misreguarded and the related socio-economic impacts must be considered.
The aim of the PhD project (which is connected to the Energy Center goals and founded by the Energy Center Lab) is in developing a methodology for building performance assessment that must be multi-disciplinary (accounting for energy, Indoor Environmental Quality and economy), while defining innovative and/or multi-domains KPIs of interest of the different stakeholders involved in the building management/retrofit process. To reach this goal the research is arranged around two subjects: "Building representation and modelling" and "Evaluation and Decision-making". The latter is connected to the provision of tools based on basic data and financial assessment for a preliminary evaluation of a retrofit project, both in terms of interventions prioritization and potential savings from alternative measures. However, the innovative contribution in this area lays in the shift towards socio-economic evaluations, focusing on the Cost-Benefit Analysis (CBA). Its application both to the district and the building level allows to account for co-benefits in the evaluation process, which is enriched thanks to monitored data.
Accordingly, the analysis of data for building characterization is the core of my research activity connected to "Building representation and modelling" subject. In particular, the relevance of the knowledge extracted from monitored data in defining archetypes for buildings modelling at various special scales is explored from energy, IEQ and occupant-related perspectives.



Project evaluation framework relying on monitored data and accounting for internal and external benefits.

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

Topic: Modeling innovative HTS conductors for fusion applications

Course year: 3rd **Tutor(s)**: Laura Savoldi, Roberto Zanino

Academic context

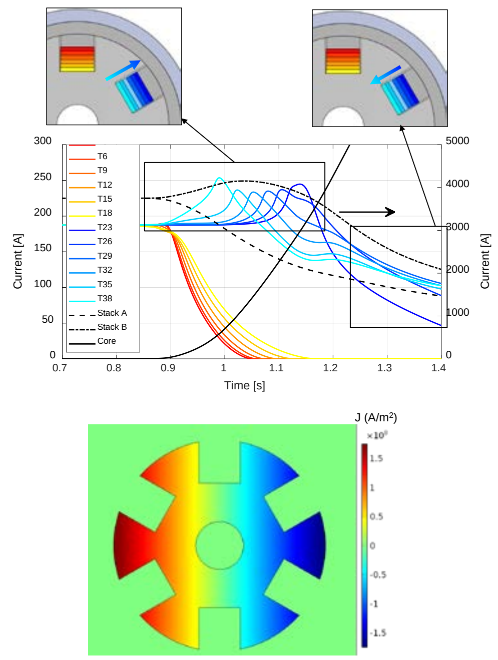
[1] A. Zappatore, W. H. Fietz, R. Heller, L. Savoldi, M. J. Wolf and R. Zanino, A critical assessment of thermal–hydraulic modeling of HTS twisted-stacked-tape cable conductors for fusion applications, *Supercond. Sci. Technol.* **32** (2019) 084004
[2] A. Zappatore, R. Heller, L. Savoldi, M. J. Wolf and R. Zanino, A new model for the analysis of quench in HTS cable-in-conduit conductors based on the twisted-stacked-tape cable concept for fusion applications, *Supercond. Sci. Technol.* **33** (2020) 065004
[3] A. Zappatore, A. Augieri, R. Bonifetto, G. Celentano, L. Savoldi, A. Vannozzi and R. Zanino, Modeling Quench Propagation in the ENEA HTS Cable-In-Conduit Conductor, *IEEE Trans. Appl. Supercond.* **30** (2020) 4603307.

External collaborations

- Karlsruhe Institute of Technology (KIT)
- ENEA
- Swiss Plasma Center (SPC)

Highlights of the research activity

The first H4C code [1] applications to the quench analysis in the KIT [2] and ENEA [3] High Temperature Superconducting (HTS) Cable-In-Conduit Conductor were presented in the previous annual report.
The third year of the PhD has been devoted to the further development of the H4C code and to the support of the ENEA conductor sample design in view of their experimental quench. The further development of the code made it flexible enough to model several conductors in the same transient. This capability enables the modeling of entire magnets made (entirely or in part) with HTS conductors. A first application has been the study of the quench propagation in the hybrid Central Solenoid designed for the EU DEMO. This magnet features both HTS and LTS conductors and it has been shown how a quench in the HTS layers could induce a quench also in the LTS layers.
On the other hand, a more detailed model of the ENEA conductor with respect to that in [3] was developed. The model helped defining the best arrangement of the diagnostics (voltage taps, temperature sensors) in the experiment as well as understanding some key features of the quench propagation in these conductors. Thanks to the more refined conductor model, it was possible to observe how the current is expected to be transferred among the tapes in the same slot and among different slots, see the top figure. In addition, another possible way to induce the quench during the experiment will be through a pulse of the background magnetic field, inducing AC losses in the conductor. A dedicated electromagnetic model, see the bottom figure, was developed, confirming that a 2 T pulse should be sufficient to induce a quench.



(Top) Evolution of the current in the HTS tapes in one of the ENEA conductor samples. (Bottom) Distribution of the current density in the core of the ENEA conductor during an AC pulse.