

David Tomás Sánchez Martínez
Lourdes García Rodríguez
(coordinadores)

Proceedings of the 7th International Seminar on

ORC

Power Systems

Editorial Universidad de Sevilla

Proceedings of the 7th International Seminar on

ORC

Power Systems

David Tomás Sánchez Martínez

Lourdes García Rodríguez

(coordinadores)

Proceedings of the 7th International Seminar on

ORC

Power Systems

(ORC2023)

**4th to 6th
SEPTEMBER
SEVILLE 2023**

 **EDITORIAL
UNIVERSIDAD DE SEVILLA**

Sevilla, 2024

Comité editorial de
la Editorial Universidad de Sevilla:

Araceli López Serena
(Directora)

Elena Leal Abad
(Subdirectora)

Concepción Barrero Rodríguez
Rafael Fernández Chacón
María Gracia García Martín
María del Pópulo Pablo-Romero Gil-Delgado
Manuel Padilla Cruz
Marta Palenque
María Eugenia Petit-Breuilh Sepúlveda
Marina Ramos Serrano
José-Leonardo Ruiz Sánchez
Antonio Tejedor Cabrera

Review chairs of the 7th International Seminar on ORC Power Systems

Prof. Christoph Wieland (University of Duisburg-Essen) - *Review Chair*

Prof. Sotirios Karellas (National Technical University of Athens) - *Review Co-Chair*

Prof. Teemu Turunen-Saaresti (LUT University) - *Review Co-Chair*

Dr. Diego-César Alarcón-Padilla (Plataforma Solar de Almería - CIEMAT) - *Review Co-Chair*

Dr. Francesco Crespi (Universidad de Sevilla) - *Review Co-Chair*

Esta obra se distribuye con la licencia

Creative Commons Atribución-NoComercial-SinDerivadas 4.0 Internacional ([CC BY-NC-ND 4.0](https://creativecommons.org/licenses/by-nc-nd/4.0/))



Usted es libre de:

Compartir — copiar y redistribuir el material en cualquier medio o formato

La licenciente no puede revocar estas libertades en tanto usted siga los términos de la licencia

Bajo los siguientes términos:

Atribución — Usted debe dar crédito de manera adecuada, brindar un enlace a la licencia, e indicar si se han realizado cambios . Puede hacerlo en cualquier forma razonable, pero no de forma tal que sugiera que usted o su uso tienen el apoyo de la licenciente.

NoComercial — Usted no puede hacer uso del material con propósitos comerciales .

SinDerivadas — Si remezcla, transforma o crea a partir del material, no podrá distribuir el material modificado.

No hay restricciones adicionales — No puede aplicar términos legales ni medidas tecnológicas que restrinjan legalmente a otras a hacer cualquier uso permitido por la licencia.

© Editorial Universidad de Sevilla 2024

c/ Porvenir, 27 - 41013 Sevilla.

Tlfs.: 954 487 447; 954 487 451; Fax: 954 487 443

Correo electrónico: info-eus@us.es

Web: <https://editorial.us.es>

© [David Tomás Sánchez Martínez](#) y [Lourdes García Rodríguez](#)
(coordinadores)

© De los textos, los autores 2024

ISBN 978-84-472-2745-7

DOI: <https://dx.doi.org/10.12795/9788447227457>

Diseño de cubierta y maquetación: los autores

INDEX OF CONTRIBUTIONS

ID3 - Additive manufacturing for fast prototyping of a velocity compounded radial re-entry turbine Authors: Dominik Stümpfl, Karel Ráž, Philipp Streit, Andreas P. Weiß.	13
ID4 - Thermodynamic concept of a novel recuperative two-phase power cycle process Authors: Benedikt G. Bederna, Riley B. Barta, Christiane S. Thomas.	23
ID7 - Performance analysis of a 1.5 MW Organic Rankine Cycle in a Carnot battery system for grid balancing services Authors: Robin Tassenoy, Hannes Van De Velde, Kenny Couvreur, Michel De Paepe, Steven Lecompte.	33
ID8 - Calibration of multi-hole probes for measurements in compressible organic vapor flows Authors: Leander Hake, Stephan Sundermeier, Stefan Aus Der Wiesche, Maximilian Passmann.	43
ID9 - pocketORC: A browser-based calculator for teaching organic Rankine cycle power systems Authors: Martin White.	53
ID10 - Evaluation of existing supercritical heat transfer correlations for designing the vapor generator in low-temperature transcritical Organic Rankine Cycle systems Authors: Jera Van Nieuwenhuyse, Anastasios Skiadopoulos, Dimitris Manolakos, Steven Lecompte, Michel De Paepe.	61
ID12 - A novel combined cooling and power cycle integrated ejector refrigeration and composition adjustment for stationary engine waste heat recovery Authors: Xiaocun Sun, Lingfeng Shi, Hua Tian, Gequn Shu.	71
ID14 - Design and construction of a reversible ORC test rig for geothermal CHP applications Authors: Florian Kaufmann, Christopher Schiffler, Christoph Wieland, Hartmut Spliethoff.	81
ID15 - Robust and fast meanline methodology for radial inflow turbines with non-ideal gases for system level optimisation of organic Rankine cycles Authors: Carola Freytag, Eva Alvarez-Regueiro, Pablo Ale-Martos, Esperanza Barrera-Medrano, Ricardo Martinez-Botas.	91
ID16 - Shape optimization of a sCO ₂ centrifugal compressor stage Authors: Alessandro Romei, Paolo Gaetani, Giacomo Persico.	101
ID17 - Optimizing the performance of a hybrid solar-biomass micro-CHP system with a TFC engine as the prime mover for domestic applications Authors: Anastasios Skiadopoulos, Xander Van Heule, Steven Lecompte, Michel De Paepe, Dimitrios Manolakos.	109
ID19 - Systematic and multi-criteria optimisation of subcritical thermally integrated Carnot batteries (TI-PTES) in an extended domain Authors: Antoine Laterre, Olivier Dumont, Vincent Lemort, Francesco Contino.	119

ID20 - ORC technology used in a heat removal system for an advanced nuclear power plant Authors: Guillaume Lhermet, Benoit Payebien, Nicolas Tauveron, Nadia Caney, Franck Morin	130
ID22 - Assessment of trilateral Organic Rankine Cycle for solar applications with innovative turboexpander concept Authors: Alessandro Romei, Andrea Giostri, Andrea Spinelli.	140
ID25 - Evaluation of the performance of an axial one-stage 10kW turbogenerator through experimental testing Authors: Piotr Klimaszewski, Piotr Klonowicz, Lukasz Witanowski, Tomasz Suchocki, Piotr Lampart, Eugeniusz Ihnatowicz, Lukasz Antczak, Dawid Zaniewski, Lukasz Jedrzejewski	149
ID26 - Investigation of the turbulence level and the vortex shedding in a turbine cascade working with an organic vapor at subsonic Mach numbers Authors: Leander Hake, Stephan Sundermeier, Stefan Aus Der Wiesche, Camille Matar, Paola Cinnella, Xavier Gloerfelt	159
ID27 - A novel approach to district heating: using a two-phase expander in a reversible heat pump-Organic Rankine Cycle system Authors: Sindu Daniarta, Attila R. Imre, Piotr Kolasinski	169
ID28 - Optimization of a partially evaporating Organic Rankine Cycle with thermal non-equilibrium expansion Authors: Xander Van Heule, Tasos Skiadopoulos, Dimitris Manolakos, Michel De Paepe, Steven Lecompte	176
ID29 - Cost-effective option of cold energy utilization in pharmaceutical industry Authors: Sindu Daniarta, Dawid Sowa, Ádám Havas, Attila R. Imre, Piotr Kolasinski	184
ID30 - Numerical investigation of a transonic dense gas flow over an idealized blade vane configuration Authors: Aurelien Bienner, Xavier Gloerfelt, Paola Cinnella, Leander Hake, Stefan Aus Der Wiesche	193
ID31 - Comprehensive analysis of ORC-VCC system for air conditioning from low-temperature waste heat Authors: Lukasz Witanowski	203
ID33 - Pareto front analysis for the design and the working fluid selection in ORC-based pumped thermal energy storage technology in both pure electric and cogenerative applications Authors: Marco Astolfi, Dario Alfani, Andrea Giostri	214
ID36 - Evaluating the waste heat sources in a very large crude carrier and the potential integration of Organic Rankine Cycle configurations Authors: Amalia Stainchaouer, Christopher Schiffler, Christoph Wieland, Hartmut Spliethoff	224
ID37 - Investigating R1234ze and R1234yf as replacements to R134a in waste heat recovery ORC applications Authors: James Bull, James Buick, Jovana Radulovic	234

ID38 - Performance and economic assessment of a thermally integrated reversible HP/ORC Carnot battery applied to data centers Authors: Chiara Poletto, Andrea De Pascale, Saverio Ottaviano, Olivier Dumont, Maria Alessandra Ancona, Michele Bianchi	244
ID39 - Evaluation of the performance of multiple supercritical CO ₂ power cycles in Waste Heat Recovery applications Authors: Hicham Chibli, Matthew Read, Abdalnaser Sayma	254
ID40 - Design and modeling of a demonstration-scale ORC cycle for the Liquid Air Combined Cycle Authors: Owen Pryor, William Conlon, Aaron Rimpel, Milton Venetos.....	264
ID41 - Guidelines and optimization criteria of a machine learning-based methodology for mixture design in ORC systems Authors: Valerio Mariani, Saverio Ottaviano, Andrea De Pascale, Giulio Cazzoli, Lisa Branchini, Gian Marco Bianchi	273
ID45 - Potential of trigenerative Waste Heat Recovery CO ₂ -mixture transcritical power plants for increasing the sustainability of district heating and cooling networks Authors: Mattia Baiguini, Michele Doninelli, Ettore Morosini, Dario Alfani, Gioele Di Marcoberardino, Paolo Giulio Iora, Giampaolo Manzolini, Costante Mario Invernizzi, Marco Astolfi	282
ID46 - Thermodynamic analysis of a novel pumped thermal energy storage system with waste heat integration Authors: Meiyang Zhang, Lingfeng Shi, Peng Hu, Gang Pei, Gequn Shu	294
ID48 - Pressure profile optimisation of a nozzle for wet-to-dry expansion Authors: Pawel Ogrodniczak, Abdalnaser Sayma, Martin T. White.....	304
ID51 - Thermodynamic modification of CO ₂ -based combined cooling and power cycle with ejector Authors: Yonghao Zhang, Lingfeng Shi, Gequn Shu	313
ID53 - Selection of suitable working fluid and storage material for ORC coupled with Thermal Energy Storage Authors: Dawid Sowa, Sindu Daniarta, Piotr Kolasinski	323
ID54 - Influence of dopant fluorination on the heat transfer behaviour of CO ₂ -based mixtures in transcritical power cycles Authors: Michele Doninelli, Gioele Di Marcoberardino, Costante Mario Invernizzi, Paolo Giulio Iora	333
ID57 - On air-cooled condensers for ORC systems operating with zeotropic mixtures Authors: Lorenzo Galieti, Carlo De Servi, Dario Alfani, Paolo Silva, Paola Bombarda, Piero Colonna	344
ID58 - Experiments on supersonic ORC nozzles in linear cascade configuration Authors: Marco Olivetti, Marco Manfredi, Giacomo Persico, Andrea Spinelli, Paolo Gaetani, Vincenzo Dossena	354
ID59 - Numerical analysis of aerodynamics and performance of a radial-inflow micro-ORC turbine Authors: Fatemeh Ardaneh, Marta Zocca, Antti Uusitalo, Teemu Turunen-Saaresti.	363

ID61 - ORC system using R1233zd(E) for waste heat recovery from the upstream process Authors: Meng Soon Chiong, Bemgba Nyakuma, Nur Izwanne Mahyon, Srithar Rajoo, Eva Alvarez-Regueiro, Maria Esperanza Barrera-Medrano, Ricardo F. Martinez-Botas, Yossapong Laoonual	373
ID63 - Experimental investigation of a small-scale reversible high temperature heat pump – Organic Rankine Cycle system for industrial Waste Heat Recovery Authors: Rahul Velanparambil Ravindran, Donal Cotter, Christopher Wilson, Ming Jun Huang, Neil Hewitt.	381
ID64 - Technical comparison and evaluation of a Pumped Thermal Energy Storage with two different designs Authors: Márcio Santos, Jorge André, Ricardo Mendes, José Ribeiro.	391
ID68 - The potential of CO ₂ -Plume Geothermal (CPG) Systems for CO ₂ component manufacturers: opportunities and development needs Authors: Christopher Schiffler, Jasper De Reus, Hartmut Spliethoff, Martin O. Saar, Sebastian Schuster, Dieter Brillert	400
ID69 - Development of a generalised low-order model for twin-screw compressors Authors: Florian Kaufmann, Ludwig Irrgang, Christopher Schiffler, Hartmut Spliethoff.	410
ID71 - Decision-making matrix for the selection of mixture in ORC applications Authors: William Combaluzier, Nicolas Tauveron, Michel Beaughon, Aldo Serafino.	420
ID72 - Reversible heat pump-ORC pilot plant – Experimental results and fluid charge optimization Authors: Maximilian Weitzer, Sebastian Kolb, Dominik Müller, Jürgen Karl	430
ID73 - Performance of Organic Rankine Cycle system in combination with residual municipal solid waste gasification: a simulation analysis Authors: Luca Cioccolanti, Giovanni Biancini, Ramin Moradi, Luca Del Zotto, Matteo Moglie	439
ID74 - Enhancing knowledge of engineering students at all levels on organic rankine cycle systems for their application in the built environment Authors: Luca Cioccolanti, Ramin Moradi, Ermira Abdullah, Syamimi Saadon, Mohamad Yusof Idroas, Teoh Yew Heng, Kwanchai Kraitong	449
ID75 - Studying carbon dioxide and acetone mixtures in a single-stage absorption-compression cycle for heating and cooling applications Authors: Jesús Gómez-Hernández, Ali Kholghi, Mercedes De Vega, Javier Villa, Ronan Grimes	458
ID77 - Valorising thermal composite recycling processes using Organic Rankine Cycles for combined heat and power applications Authors: Ramin Moradi, Liu Yang	466
ID80 – Prediction of the ideal maximum operational temperature of hydrocarbon and HFCs as working fluids of Organic Rankine Cycle power plants based on transition state theory Authors: Wei Yu, Chao Liu, Xijie Ban, Zhirong Li, Tianlong Yan	476
ID82 - Comparison of different evaporator topologies for industrial heat pumps Authors: Sanjay Vermani, Nitish Anand, Johan Van Bael, Evgueni Toulankine, Aldo Serafino, Carlo De Servi.	486

ID83 - On the plant improvement of Solar-driven ORC based power unit for domestic microcogeneration Authors: Fabio Fatigati, Marco Di Bartolomeo, Arianna Coletta, Diego Vittorini, Giammarco Di Giovine, Davide Di Battista, Roberto Cipollone.	496
ID84 - Mapping the techno-economic potential of next-generation CSP plants running on transcritical CO ₂ -based power cycles Authors: Pablo Rodríguez-deArriba, Francesco Crespi, Sara Pace, David Sánchez	505
ID86 - Achieving 45% micro gas turbine efficiency through hybridization with Organic Rankine Cycles Authors: Antonio Escamilla, David Sánchez Martínez, Lourdes García-Rodríguez	515
ID88 - Operational optimisation of the main heat rejection unit of CSP plants based on carbon dioxide mixtures Authors: Francesco Crespi, Pablo Rodríguez-deArriba, Lourdes García-Rodríguez, David Sánchez.	525
ID89 - Mechanical design and rotor-dynamic analysis of the ORCHID turbine Authors: Matteo Majer, Steven Chatterton, Ludovico Dassi, Alessio Secchiaroli, Edoardo Gheller, Carlo De Servi, Paolo Pennacchi, Piero Colonna, Matteo Pini.	535
ID91 - Thermodynamic feasibility of a pumped thermal energy storage driven by ocean temperature gradient Authors: Alessandra Ghilardi, Andrea Baccioli, Guido Francesco Frate, Lorenzo Ferrari	545
ID92 - Exergy-based methods for heat pumps Authors: Mathias Hofmann, Jonas Freißmann, Malte Fritz, Jeremias H. Alexe, Francesco Witte, George Tsatsaronis	553
ID93 - Reduced order modelling of optimized heat exchangers for maximum mass-specific performance of Airborne ORC Waste Heat Recovery units Authors: Fabio Beltrame, Dabo Krempus , Piero Colonna, Carlo De Servi.	563
ID97 - Basic design of an ORC demonstrator system for implementation in an Iron & Steel plant through the DECAGONE project Authors: Magnus Windfeldt, Han Deng, Trond Andresen, Christopher Schifflachner	574
ID98 - Analytical estimation of the presence of non-condensable gases in the condensate tank of an Organic Rankine Cycle Authors: Radheesh Dhanasegaran, Antti Uusitalo, Juha Honkatukia, Teemu turunen-Saaresti	584
ID101 - Advanced control of compressor inlet temperature in supercritical CO ₂ Brayton cycle Authors: Rui Wang, Xuan Wang, Hua Tian, Gequn Shu.	596
ID103 - Potential for surplus-heat-to-power conversion in current and future aluminium production processes with off-gas recycling Authors: Jonas Bueie, Magnus Windfeldt, Trond Andresen.	605
ID104 - Investigating the application range of ORC power plants for the exploitation of two-phase geothermal resources Authors: Tristan Merbecks, Claudio Pietra, Paola Bombarda, Martin O. Saar, Paolo Silva, Dario Alfani.	615
ID109 - Cold Energy Recovery in LNG plants with Organic Rankine Cycle Authors: Gabriele Marchiori, Marta Giudici, Giorgia Ruffato, Marco Astolfi	626

ID110 - Numerical investigation of organic vapor flow effects on a micro-scale radial turbocompressor Authors: Andrés Sebastián, Rubén Abbas, Manuel Valdés	636
ID112 - Design, modeling and simulation of an experimental Rankine PTES system Authors: Mario Petrollese, Giorgio Cau, Matteo Marchionni, Marcello Lorenzo Marroccu, Rosa Merchan	645
ID113 - Small-scale turbopumps for Waste Heat Recovery applications based on an Organic Rankine Cycles, modeling, analytical and experimental investigation Authors: Sajjad Zakeralhoseini, Jürg Schiffmann	655
ID116 - Double-stage ORC system based on various temperature waste heat sources of the negative CO2 power plant Authors: Kamil Stasiak, Pawel Ziolkowski, Dariusz Mikielewicz	665
ID117 - Optimization of organic Rankine cycle in ocean thermal energy conversion based on NSGA-II Authors: Zheng Hu, Jiufa Chen, Bing Guo, Chengbin Zhang	679
ID118 - TES4Trig: Development of a demonstrator for the production of electricity, heating and cooling based on an Organic Rankine and an Ejector Cooling Cycle driven by high-temperature parabolic trough collectors with thermal energy storage Authors: Konstantinos Braimakis, Dimitrios Tziritas, George Stavrakakis, Julio Terrón Gutiérrez, Siddhart Dutta, Christos Xynos, Panagiotis Zervas, Sotirios Karellas	689
ID119 - Simulation and operation of a CSP that works with a HRB Cycle Authors: Antonio J. Subires, Antonio Rovira	701
ID123 - Towards a green energy community: integration of micro-ORCs combined with renewable energy technologies in buildings Authors: Diego Antonio Rodríguez Pastor, Víctor Manuel Soltero Sánchez, Elisa Carvajal Trujillo, José Antonio Becerra, Ricardo Chacartegui	713
ID129 - Assessment of high temperature heat pump layouts equipped with a bladeless turboexpander Authors: Matteo Passalacqua, Simone Maccarini, Stefano Barberis, Alberto Traverso	723
ID133 - Selection of the optimal working fluid in an Organic Rankine Cycle for Waste Heat Recovery through multi-objective optimization and decision making Authors: Bipul Krishna Saha, El Mouatez Billah Messini, Syed J. Hoque, B Aneesh Bhat, Pramod Kumar	733
ID139 - Dual condensing pressure ORC for cryogenic energy storage Authors: William M. Conlon, Milton J. Venetos	743
ID141 - Optimum coupling of thermal energy storage and power cycles for Carnot batteries Authors: Salvatore Guccione, Rafael Guede	751
ID142 - Aerodynamic design and numerical analysis of a counter-rotating centrifugal compressor Authors: Cheikh Brahim Abed, Arthur Leroux	761

Toward a Green Energy Community: Integration of micro-ORCs combined with renewable energy technologies in buildings.

Diego Antonio Rodríguez-Pastor^{*,1}, Víctor Manuel Soltero Sánchez², Elisa Carvajal Trujillo¹, José Antonio Becerra¹, Ricardo Chacartegui¹

¹ *University of Seville, Escuela Técnica Superior de Ingenieros, Camino de los Descubrimientos s/n, 41092 Seville, Spain*

² *University of Seville, Escuela Politécnica Superior, 41011, Seville, Spain*

*Corresponding author: drodriguez4@us.es

ABSTRACT

Distributed microgeneration is an alternative for aggregate energy integration into the electricity grid. Low-temperature heat recovery systems, such as ORCs, are particularly interesting given their compactness and safety for application in the residential sector, operating at moderate pressures and low heat source temperatures. Energy surpluses generated by renewable technologies commonly used in the building sector, such as photovoltaics or micro-wind, can be used to power systems that provide backup and add inertia to the grid. In this study, micro-ORCs (< 2 kWe) were integrated with different heat supply technologies in buildings, including storage with DHW water tanks or sensible heat in bedrock for heating. An overview of possible configurations and techno-economic optimization is provided, offering combined strategies with other installations and additional characterization of energy communities with a larger number of connected neighbors, determining optimized integrations for covering thermal and electrical demands.

713

1 INTRODUCTION

As global concerns regarding climate change and environmental degradation have increased, there is a growing need to transition to sustainable and renewable energy sources (IEA, 2022). Integrating energy communities in rural areas has emerged as a promising solution for increasing sustainability, promoting the use of renewable energy sources, and reducing carbon emissions (Koirala et al., 2016; Streimikiene et al., 2021). By leveraging local renewable energy resources and fostering cooperation between energy users and producers, energy communities can contribute significantly to achieving a sustainable energy future (Bassam, 2021). Furthermore, the integration of renewable energy technologies into residential buildings is a critical component of this transition (Klein & Coffey, 2016), and the cost-efficient implementation of cogeneration (CHP) systems in single-family homes represents a significant step towards achieving this goal (Ceglia et al., 2022a).

The integration of organic Rankine cycles (ORC) in single-family homes is presented as a promising option for the generation of electricity from residual thermal energy produced by, for example, the time gap between demand and the generation of domestic solar hot water (Ancona et al., 2022; Pereira et al., 2018a). (Rodríguez-Pastor et al., 2023) analysed the optimal sizing of ORCs for solar domestic hot water systems, depending on the demand and solar resources available at the site, and reported improvements in the efficiency of solar collectors owing to a lower fraction of cold-water mixing. (Braumakis et al., 2021) studied centralized scenarios incorporating district heating systems that further enhance the performance and feasibility of ORC systems. Using low-grade waste heat, such as solar domestic hot water systems (Bou Lawz Ksayer, 2011), the ORC system can produce electricity while simultaneously providing heat to the building through the District Heating network.

Energy communities are groups of households, businesses, or other entities collaborating to generate, consume, and share energy locally (Andoura et al., 2010). By leveraging surplus thermal energy from

systems such as domestic hot water with storage for electricity generation, ORC systems can contribute to the development of sustainable and self-sufficient energy communities (Alberto et al., 2022; Ceglia et al., 2022b). They can reduce dependence on the electric grid, promote energy independence, and enhance local resilience to power outages and disruptions (Dóci et al., 2015). They can also optimise the utilisation of surplus thermal energy, which would otherwise go to waste, by converting it into electricity, thus improving energy efficiency and reducing the environmental impact (Baral et al., 2015). Additionally, energy communities can promote social cohesion, participation, and empowerment among their members as they jointly participate in energy production and consumption decisions (Lowitzsch et al., 2020). However, there are also associated challenges and considerations, including regulatory and legal frameworks, technical complexities of power production system installation and operation (Loni et al., 2021; Pereira et al., 2018b), financial aspects such as investment costs and revenue sharing among community members (Busch et al., 2021), and potential disparities in energy demand and supply among different households or entities within the community (Frieden et al., 2020). Addressing these challenges requires careful planning, coordination, and stakeholder engagement (Mishra et al., 2022).

This study aimed to analyze the technical and economic feasibility of integrating ORC systems into single-family homes in southern Spain in decentralized and centralized scenarios. This study focuses on analyzing the potential for the use of waste heat from solar hot water systems to generate electricity and provide heating to buildings. A detailed techno-economic analysis of the ORC system and SDHW was conducted by considering different configurations and operating conditions. These results provide valuable information to policymakers, energy planners, and homeowners regarding the adoption and implementation of ORC systems in the residential sector.

2 SYSTEM DESCRIPTION

In a decentralized system integrating ORCs in the residential sector, each household or residential unit has its own installed micro-ORC, which uses surplus thermal energy from its domestic hot water system with storage to generate electricity (**Figure 1**). This approach involves the installation of smaller capacity micro-ORC systems in each household or residential unit. Each micro-ORC can operate autonomously and generate electricity in individual operation (Physical System). The excess electricity produced can be injected into the grid, allowing the possibility of earning income by selling energy to the grid. This decentralized approach offers advantages in terms of energy autonomy for each residential unit.

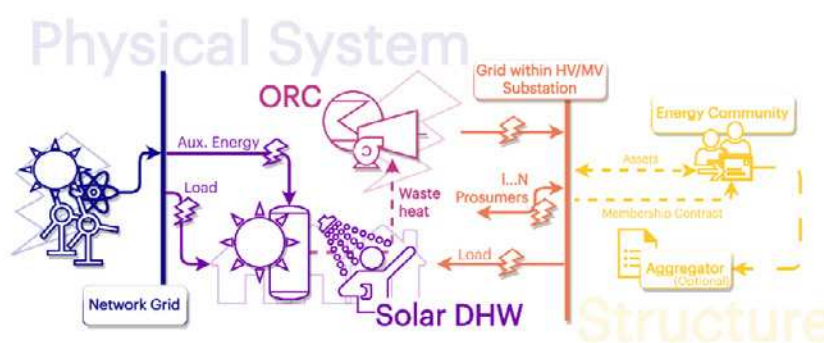


Figure 1. Conceptual diagram of the proposed decentralised ORC-SDHW system

In contrast, in a centralized system integrating ORCs in the residential sector, a higher-capacity ORC is installed in a central location, which can be a community facility or power generation plant (**Figure 2**).

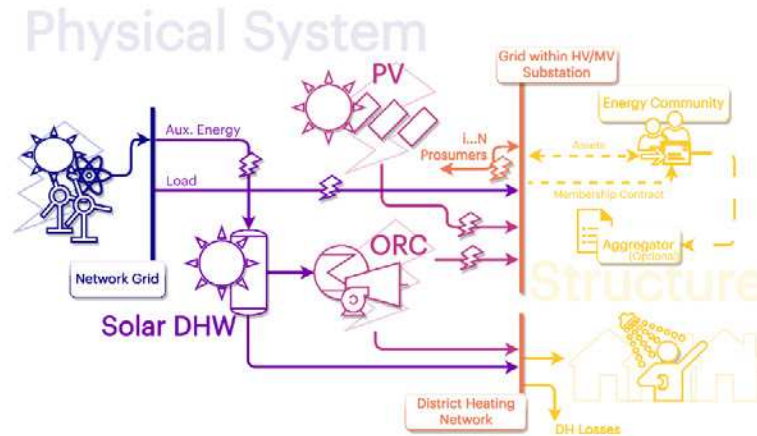


Figure 2. Conceptual diagram of the proposed centralised ORC-SDHW system

For the centralized approach presented, the central ORC system harnesses residual energy from industrial thermal processes or utilizes solar thermal energy for domestic hot water systems during periods of low demand or high solar resource, resulting in a decrease in the flow rate of the cold-water mix and a consequent increase in the performance of solar collectors. The central ORC can operate more efficiently and cost-efficiently because of its economy of scale, with a reduced kilowatt cost and better control and management of electricity generation. The produced electricity can be injected into the grid and distributed to households or residential units in a zone or community. This centralized approach offers advantages in terms of efficiency, economics, and management of electricity generation on a larger scale, as discussed. In a decentralized system, each household or residential unit has its own micro-ORC for local electricity generation, whereas in a centralized system, a higher-capacity ORC is used at a central location to harness surplus thermal energy from multiple households or residential units in a zone or community. Both approaches have advantages and challenges, and the choice between them depends on the specific needs and characteristics of the project or application under consideration, where the management of production/generation is provided by a contractual structure system (Structure).

In this study, the R245fa fluid was selected based on the criteria of condensing at atmospheric pressure at temperatures on the order of ambient temperature. This allows for greater flexibility in installation, considering that the facility is applied in a residential environment.

3 SIMULATION

Figure 3 shows the proposed system. This was simulated using the commercial software TRNSYS (S.A Klein, 2017). For this purpose, an ORC type was created that modelled the ORC cycle based on the values of the parameters in **Table 1**.

Table 1. Thermodynamic considerations for power system simulation.

Variable	Value
Heat Exchangers approach temperature	20 K
Isentropic efficiency of pump	50%
Isentropic efficiency of expander	60%
Maximum refrigerant pressure	$0.85 \cdot p_{crit}$
Storage setpoint temperature for ORC start-up.	75 °C

Refrigerant property calculations are performed through a subroutine that calls Coolprop (Bell et al., 2014), obtaining the associated power production in the expander at each time step. Several articles

have employed this methodology, such as the studies by (Ancona et al., 2022). The following considerations and assumptions have been considered for the calculation of the power system in residential ORC systems with solar hot water systems. i) The minimum water outlet temperature of the ORC evaporator is 60°C to avoid penalizing the demand. ii) The mass flow rate of the refrigerant varied according to the waste heat power of the SDHW system to satisfy the energy balance in each case. iii) The calculations were performed in a quasi-dynamic regime. iv) The temperature of the cold fluid used for condensation is 25°C.

The TRNSYS simulations use Types 4 and 1 to represent the storage tank and collectors, respectively. The system equations will be simplified algebraically within TRNSYS, where the collector efficiency is described by three parameters (a_0 , a_1 , and a_2) in accordance with ASHRAE, SRCC, and CEN standards.

$$\eta_{coll} = a_0 - a_1 \frac{\Delta T}{I_T} - a_2 \frac{(\Delta T)^2}{I_T} \quad (1)$$

The collector area is determined by the volume/area ratio of 50 l/m², where the storage volume is designed to cover 1.5 times the total daily demand (Duffie & Beckman, 1991). The demand will be calculated according to the Spanish regulation standard, which is 28 l/s·person·day at a temperature of 60°C (Ministerio de Fomento, 2019).

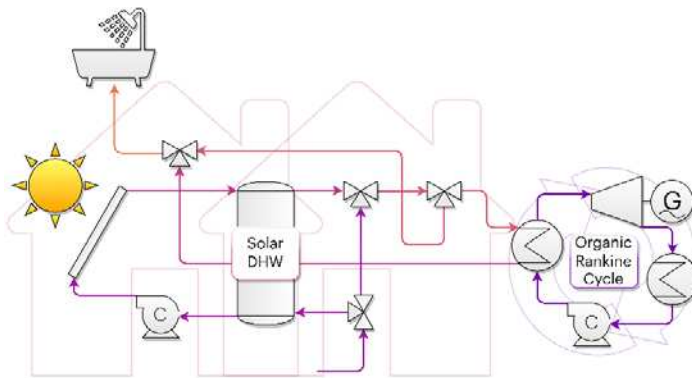


Figure 3. Flow diagram of the proposed SDHW-ORC system

Meteorological data from Seville (-5.9731700°; 37.3828300°) were used, considering the variation in demand associated with the occupancy of the residence in the decentralized case and for several residences of four people in the centralized case. **Table 2** lists the thermodynamic parameters that describe the solar-loop components.

Table 2. Thermodynamic parameters of the solar collectors

Parameter	Value	Units
Fluid specific heat	4.19	<i>kJ/kg.K</i>
Tested flow rate	0.011	<i>kg/s.m²</i>
Intercept efficiency (a_0)	0.801	-
Efficiency slope (a_1)	3.93	<i>W/m².K</i>
Efficiency curvature (a_2)	0.026	<i>W/m².K²</i>
1st-order IAM	0.2	-

These values were used to evaluate the technical and economic feasibility of the installation and its integration in an energy community context. No subsidies or grants were considered in the analyses. The objective is to provide correlation coefficients for evaluating the system based on the number of people participating in the energy community, proposing simple expressions that may be valuable for

organizations such as governments or municipalities that intend to implement ORC-based energy communities. The expressions have the following forms (Equations 2 and 3):

$$E_{DHW}^d = a_{DHW}^d + b_{DHW}^d \cdot Persons + c_{DHW}^d \cdot Persons^2 \quad (2)$$

Where E_{DHW}^d is the annual thermal demand for domestic hot water of the household in kWh.

$$E_{ORC}^d = a_{ORC}^d + b_{ORC}^d \cdot Persons + c_{ORC}^d \cdot Persons^2 \quad (3)$$

And E_{ORC}^d is the annual ORC production for the decentralised case in kWh. When forming a community considering a centralized system that supplies several residences, the expressions are as follows (Equations 4 and 5).

$$E_{DHW}^c = a_{DHW}^c + b_{DHW}^c \cdot Households + c_{DHW}^c \cdot Households^2 \quad (4)$$

Being E_{DHW}^c is the annual thermal demand for domestic hot water of the households in kWh.

$$E_{ORC}^c = a_{ORC}^c + b_{ORC}^c \cdot Households + c_{ORC}^c \cdot Households^2 \quad (5)$$

And E_{ORC}^c is the annual ORC production for the centralised case in kWh. On the other hand, the Internal Rate of Return (IRR) will be evaluated from Equation 6.

$$IRR = r \text{ when } \sum_{k=1}^n \frac{CF_k}{(1+r)^k} = 0 \rightarrow IRR^i = a_j^i + b_j^i E_{DHW}^i + c_j^i E_{DHW}^{i^2} + d_j^i E_{ORC}^i + e_j^i E_{ORC}^{i^2} \quad (6)$$

For a useful life (n) of the installation of 20 years and a discount rate (r) of 5%. Similarly, to evaluate the cost of energy, the Levelized Cost of Energy (LCOE) is used, as expressed in Equation 7:

$$LCOE = \frac{CAPEX + \sum_{k=1}^n \frac{OPEX_k}{(1+r)^k}}{\sum_{k=1}^n \frac{E_{ORC}^i}{(1+r)^k}} \quad (7)$$

$CAPEX$ being the initial investment cost of the plant, $OPEX_i$ is the annual operation and maintenance cost and E_{ORC} the annual energy produced in the ORC in kWh. Investment and maintenance costs were estimated using CEPCI (Jenkins, 2014) indices. The energy cost is determined by the wholesale price in Spain in 2022 (OMIE, 2022).

4 SUBMISSION OF MANUSCRIPT

4.1 Decentralized systems

In decentralized systems, the trend of irradiance is crucial for the correct operation of the ORC and an increase in production. This variable is directly related to the number of people living in the house, as it requires a larger solar loop size (larger area and storage) to meet the demand. The ORC production for months of high irradiation will practically double (450 kWh) for the case of maximum occupancy (six people), owing to the lack of demand and a higher thermal level than in other cases (**Figure 4, left**). On the right side of **Figure 4**, the points are displaced according to the number of people and associated demand for domestic hot water. This shows that, in many solar DHW systems, there is a significant excess of energy that is not used and is lost when hot water is mixed with cold water from the main source. This was deduced from the amount of energy produced in the ORC from the waste heat in solar DHW systems. For a setpoint temperature of 60 °C, according to the regulations governing these systems, there is a thermal resource at the outlet that can be used in a simple way through the ORC

evaporator, designed such that it does not affect the demand in this case, and that the consumer receives domestic hot water at the temperature that he/she establishes.

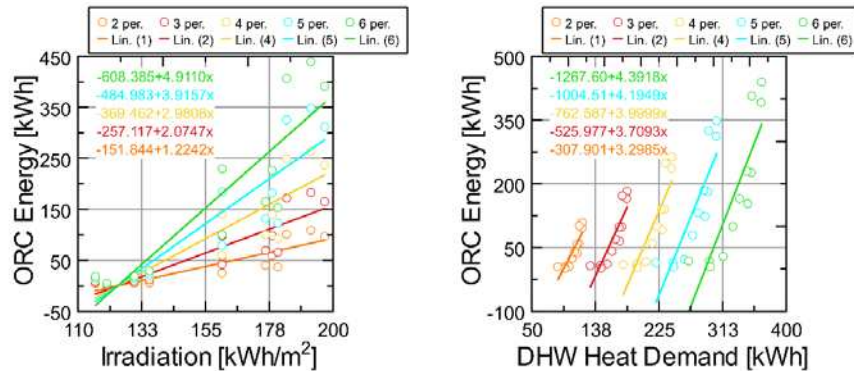


Figure 4. Monthly ORC energy production as a function of the number of people in the household and left: monthly incident irradiation (kWh/m²) and right: monthly domestic hot water demand (kWh)

From an economic point of view, ORCs still have challenges to be fully competitive on a small scale, with costs of 45 cents/kWh, more than twice that of photovoltaic systems without storage, and even above those with batteries (Lazard, 2023). Cost reductions may occur with a greater number of people to supply and optimised management of the available heat. An increase of 500 kWh in the ORC production per year may decrease the associated LCOE by 10 cents until it stabilizes (**Figure 5, left**). This also applies to the net present value (NPV), which reaches a maximum of five people (2300 €) and then decreases. Therefore, there is a strong correlation between the demand and annual production (**Figure 5, right**), which can take advantage of almost half of the energy applied to the demand in ORC production. As the heat demand increases, the net present value will eventually stabilize, as the sizing of the ORC will have to increase, and the cost correlations will be different from those considered in the micro-ORC field. In this sense, it is of interest to opt for centralized configurations, as discussed in the next section.

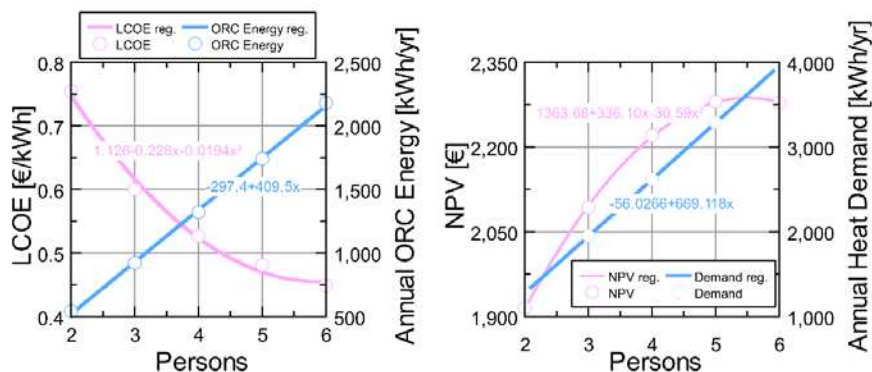


Figure 5. Regressions as a function of the number of people living in the house for the left, LCOE (€/kWh), and annual energy produced by ORC (kWh/yr); and right, net present value (€) and annual heat demand (kWh/yr).

4.2 Centralized systems

For centralized systems, the investment cost associated with the Rankine cycle is lower because of economies of scale as well as the establishment of different energy production strategies and better power cycle efficiencies. Thus, as occupancy increased, the technical and economic feasibility became

more notable (**Figure 6**). Thus, for the centralised case, the LCOE can already be competitive (€0.25/kWh), including both storage and joint production of domestic hot water, with some community photovoltaic installations (€0.18/kWh) provided by (Lazard, 2023). From 10 houses (40 persons) in the energy community, integration became viable from the point of view of $IRR > r$, where net present values (NPV) became greater than the investment cost (**Figure 6, bottom**).

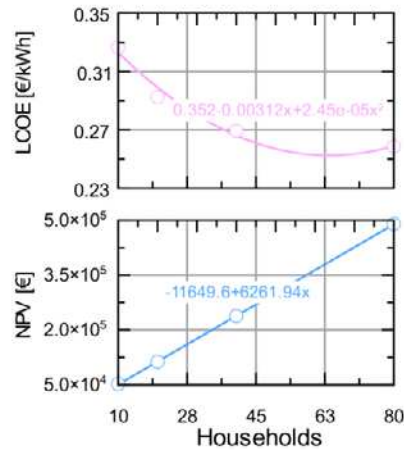


Figure 6. Regression of the LCOE and NPV as a function of the number of households associated with the energy community.

These levelized cost values indicate a great interest in the proposed configuration, as it proposes a system that can be competitive with solar photovoltaic energy communities (<35% difference compared to energy communities based on photovoltaics), where a system with storage (water tank) and a dual use of energy both in thermal form (DHW) and in electrical form through the ORC is also proposed. High cogeneration efficiencies were obtained for the central plant with the solar ORC, reaching their maximum for 66 houses for the studied configuration. Beyond this point, the cost of storage increases exponentially, and its average temperature decreases. Therefore, it is recommended to section the installation into several smaller ones that offer better performance (**Figure 7**). However, the trend of the IRR is linearly upward as more electrical energy is produced and the investment is returned in less time.

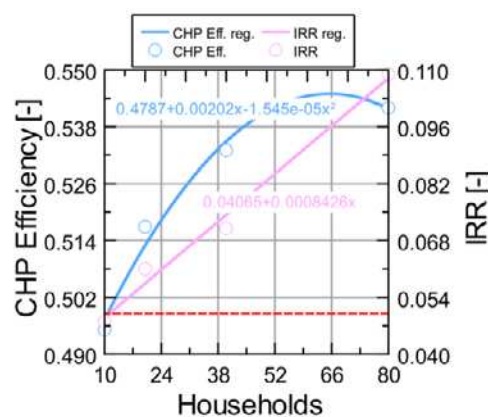


Figure 7. Cogeneration efficiency and internal rate of return as a function of the number of houses in the energy community

It is also noted that for the economic cost-effectiveness baseline (red dotted line in **Figure 7**), where $IRR > r$, the minimum number of dwellings to be covered by the community energy modality with SDHW-ORC will be at least 10-12 dwellings. In the case of lower associated demand or lower

occupancy in the energy community, smaller ORC equipment and decentralised modular configurations should be chosen.

To establish simple mathematical relationships for the technical-economic evaluation of the configurations studied, statistical correlations with a high coefficient of determination ($R^2 > 90\%$) have been carried out, which allow different hot water demand scenarios to be adapted to the associated design output in the ORC. The results obtained from the statistical fitting of the simulation are listed in **Table 3**, where they can be implemented according to the building occupancy to be applied in **Table 4** to obtain the economic feasibility of the ORC-SDHW integration. A linear trend of demand with respect to occupancy is observed, mainly given by regulatory norms in Spain and the expression of water consumption used.

Table 3. Regression coefficients for the demand for domestic hot water (kWh) and associated ORC production (kWh) as a function of occupancy in each case.

Variable	a_j^i	b_j^i	c_j^i
E_{DHW}^{dec}	1.36367779E+03	3.36101028E+02	-3.05942581E+01
E_{ORC}^{dec}	-4.15466000E+01	6.60843314E+02	1.03428571E+00
E_{DHW}^{cen}	-2.58935167E+02	2.72777354E+03	6.79019086E-02
E_{ORC}^{cen}	-3.67802467E+03	2.34557525E+03	5.83261022E-01

Table 4. Regression coefficients for obtaining IRR for each case studied.

Variable	a_j^i	b_j^i	c_j^i	d_j^i	e_j^i
IRR^{dec}	9.05291474E+02	-1.59023221E-02	4.68049936E-05	-9.55433309E-02	1.34798619E-05
IRR^{cen}	3.41658317E-02	1.70048237E-06	-	-1.58635444E-06	-

5 CONCLUSIONS

This study proposes the integration of an ORC into domestic hot water systems to evaluate its techno-economic viability. It studied a decentralised case with micro-ORC and low annual thermal demand and another case in which a group of houses are grouped into an energy community, thus establishing a central ORC system and production of DHW with solar collectors. Several important conclusions can be drawn from the results and analysis presented in this paper.

- First, it shows that the integration of the ORC in solar domestic hot water systems can be technically and economically viable, especially in centralised systems with higher thermal demand (>40 persons).
- In the decentralised case, it was found that the micro-ORC can be an interesting option for small demands, but economic viability may be limited ($IRR < 2\%$). In the centralised case (energy community), it was demonstrated that the integration of the ORC and solar collectors could result in a significant decrease in energy cost ($IRR > 10\%$) and an increase in cogeneration efficiency (>51%).
- Competitive LCOE values were obtained compared to energy communities based on photovoltaics with <35% difference, adding to our case a storage system and thermal power generation.
- In addition, the number of homes in an energy community significantly impacts the economic viability of ORC integration, with a minimum of 10 homes necessary for the project to be sufficiently profitable. Domestic hot water demand and ORC production are highly correlated, suggesting that the integration of these systems can be highly efficient because there is a large thermal resource that can be harnessed with ORC (almost half of the thermal demand for domestic hot water) instead of mixing with cold water to reach the 60 °C required by regulations.

NOMENCLATURE

E	energy	(kWh)
CF	cashflow	(€)
η	efficiency	(–)
CHP	combined heat and power	
ORC	organic Rankine cycle	
DHW	domestic hot water	
IRR	internal rate of return	(–)
NPV	net present value	(€)
LCOE	levelized cost of energy	(€/kWh)

Subscript/superscript

cen	centralised
dec	decentralised
coll	collector

REFERENCES

- Alberto, C., Ceglia, F., Davide Maria Laudiero, Alessandro, M., Marrasso, E., & Laura, V. (2022). *Energy analysis of a geothermal-based energy community equipped with heating and cooling network coupled to an ORC plant*. 0385, 1–12. <https://iris.unisannio.it/handle/20.500.12070/56499>
- Ancona, M. A., Bianchi, M., Branchini, L., De Pascale, A., Melino, F., Peretto, A., Poletto, C., & Torricelli, N. (2022). Solar driven micro-ORC system assessment for residential application. *Renewable Energy*, 195, 167–181. <https://doi.org/10.1016/J.RENENE.2022.06.007>
- Andoura, S., Hancher, L., & Van Der Woude, M. (2010). *Towards a European Energy Community: A Policy Proposal*. http://inis.iaea.org/Search/search.aspx?orig_q=RN:48094830
- Baral, S., Kim, D., Yun, E., & Kim, K. C. (2015). Energy, Exergy and Performance Analysis of Small-Scale Organic Rankine Cycle Systems for Electrical Power Generation Applicable in Rural Areas of Developing Countries. *Energies* 2015, Vol. 8, Pages 684–713, 8(2), 684–713. <https://doi.org/10.3390/EN8020684>
- Bassam, N. El. (2021). Current distributed renewable energy in rural and urban communities. *Distributed Renewable Energies for Off-Grid Communities: Empowering a Sustainable, Competitive, and Secure Twenty-First Century*, 297–326. <https://doi.org/10.1016/B978-0-12-821605-7.00024-6>
- Bell, I. H., Wronski, J., Quoilin, S., & Lemort, V. (2014). Pure and pseudo-pure fluid thermophysical property evaluation and the open-source thermophysical property library coolprop. *Ind. Eng. Chem. Res.*, 53(6), 2498–2508. <https://doi.org/10.1021/ie4033999>
- Bou Lawz Ksayer, E. (2011). Design of an ORC system operating with solar heat and producing sanitary hot water. *Energy Procedia*, 6, 389–395. <https://doi.org/10.1016/J.EGYPRO.2011.05.045>
- Braimakis, K., Charalampidis, A., & Karellas, S. (2021). Techno-economic assessment of a small-scale biomass ORC-CHP for district heating. *Energy Conversion and Management*, 247, 114705. <https://doi.org/10.1016/J.ENCONMAN.2021.114705>
- Busch, H., Ruggiero, S., Isakovic, A., & Hansen, T. (2021). Policy challenges to community energy in the EU: A systematic review of the scientific literature. *Renewable and Sustainable Energy Reviews*, 151, 111535. <https://doi.org/10.1016/J.RSER.2021.111535>
- Ceglia, F., Marrasso, E., Roselli, C., Sasso, M., Coletta, G., & Pellegrino, L. (2022a). Biomass-Based Renewable Energy Community: Economic Analysis of a Real Case Study. *Energies* 2022, Vol. 15, Page 5655, 15(15), 5655. <https://doi.org/10.3390/EN15155655>
- Ceglia, F., Marrasso, E., Roselli, C., Sasso, M., Coletta, G., & Pellegrino, L. (2022b). Biomass-Based Renewable Energy Community: Economic Analysis of a Real Case Study. *Energies* 2022, Vol. 15, Page 5655, 15(15), 5655. <https://doi.org/10.3390/EN15155655>
- Dóci, G., Vasileiadou, E., & Petersen, A. C. (2015). Exploring the transition potential of renewable energy communities. *Futures*, 66, 85–95. <https://doi.org/10.1016/J.FUTURES.2015.01.002>
- Duffie, J. A., & Beckman, W. A. (1991). *Solar engineering of thermal processes*. 919.

- Frieden, D., Tuerk, A., & Neumann, C. (2020). *Collective self-consumption and energy communities: Trends and challenges in the transposition of the EU framework*. <https://doi.org/10.13140/RG.2.2.25685.04321>
- IEA. (2022). *World Energy Outlook 2022*. www.iea.org/t&c/
- Jenkins, S. (2014). Construction-cost indices. *Chemical Engineering*, 121(6), 28–29. <https://go.gale.com/ps/i.do?p=AONE&sw=w&issn=00092460&v=2.1&it=r&id=GALE%7CA371192960&sid=googleScholar&linkaccess=fulltext>
- Klein, S. J. W., & Coffey, S. (2016). Building a sustainable energy future, one community at a time. *Renewable and Sustainable Energy Reviews*, 60, 867–880. <https://doi.org/10.1016/J.RSER.2016.01.129>
- Koirala, B. P., Koliou, E., Friege, J., Hakvoort, R. A., & Herder, P. M. (2016). Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. *Renewable and Sustainable Energy Reviews*, 56, 722–744. <https://doi.org/10.1016/J.RSER.2015.11.080>
- Lazard. (2023, April). *2023 Levelized Cost Of Energy+ | Lazard*. <https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/>
- Loni, R., Mahian, O., Markides, C. N., Bellos, E., le Roux, W. G., Kasaeian, A., Najafi, G., & Rajaei, F. (2021). A review of solar-driven organic Rankine cycles: Recent challenges and future outlook. *Renewable and Sustainable Energy Reviews*, 150, 111410. <https://doi.org/10.1016/J.RSER.2021.111410>
- Lowitzsch, J., Hoicka, C. E., & van Tulder, F. J. (2020). Renewable energy communities under the 2019 European Clean Energy Package – Governance model for the energy clusters of the future? *Renewable and Sustainable Energy Reviews*, 122, 109489. <https://doi.org/10.1016/J.RSER.2019.109489>
- Ministerio de Fomento. (2019). Código Técnico de la Edificación. Documento Básico HE Ahorro de Energía. *Código Técnico de La Edificación*, 1–129. <http://www.arquitectura-tecnica.com/hit/Hit2016-2/DBHE.pdf>
- Mishra, R., Naik, B. K. R., Raut, R. D., & Paul, S. K. (2022). Circular economy principles in community energy initiatives through stakeholder perspectives. *Sustainable Production and Consumption*, 33, 256–270. <https://doi.org/10.1016/J.SPC.2022.07.001>
- OMIE. (2022). *Market Results*. <https://www.omie.es/>
- Pereira, J. S., Ribeiro, J. B., Mendes, R., Vaz, G. C., & André, J. C. (2018a). ORC based micro-cogeneration systems for residential application – A state of the art review and current challenges. *Renewable and Sustainable Energy Reviews*, 92, 728–743. <https://doi.org/10.1016/J.RSER.2018.04.039>
- Pereira, J. S., Ribeiro, J. B., Mendes, R., Vaz, G. C., & André, J. C. (2018b). ORC based micro-cogeneration systems for residential application – A state of the art review and current challenges. *Renewable and Sustainable Energy Reviews*, 92, 728–743. <https://doi.org/10.1016/J.RSER.2018.04.039>
- Rodriguez-Pastor, D. A., Becerra, J. A., & Chacartegui, R. (2023). Adaptation of residential solar systems for domestic hot water (DHW) to hybrid organic Rankine Cycle (ORC) distributed generation. *Energy*, 263, 125901. <https://doi.org/10.1016/J.ENERGY.2022.125901>
- S.A Klein. (2017). TRNSYS 18: A Transient System Simulation Program. *Solar Energy Laboratory, University of Wisconsin, Madison, USA*. <http://sel.me.wisc.edu/trnsys>
- Streimikiene, D., Baležentis, T., Volkov, A., Morkūnas, M., Žičkienė, A., & Streimikis, J. (2021). Barriers and Drivers of Renewable Energy Penetration in Rural Areas. *Energies 2021, Vol. 14, Page 6452*, 14(20), 6452. <https://doi.org/10.3390/EN14206452>

ACKNOWLEDGEMENT

This work was partially funded by ESASUR and VS ENERGY TECH SL, a spin-off company of the University of Seville.

This book contains the compilation of works contributed to the *7th International Seminar on Organic Rankine Cycle Power Systems* (ORC 2023), held in Seville between the 4th and 6th of September 2023. The event was hosted by Universidad de Sevilla on behalf of the Knowledge Centre on Organic Rankine Cycle Technology (KCORC), incorporated in The Netherlands.

The ORC conference, organized biennially, stems as the only conference that is specific to ORC technology, therefore gathering a diverse community whose affiliation spans across all the interested stakeholders, not only in this particular technology but also and in a broader context, in the energy transition. Original equipment manufacturers, professional associations, end-users, investors, policy makers, academics, scientists feel at home at ORC 2023.

The almost 100 proceedings in this book cover a wide variety of topics, from fundamentals to system integration through component design, accounting for thermodynamic performance as well as component design. In addition to this, and as a new track in 2023, works on heat pump technology were also accepted in order to raise awareness of the strong ties between both technologies, specifically in energy storage applications.

This book provides an excellent overview of the current maturity of power systems based on Organic Rankine Cycle technology for applications as diverse as geothermal and waste heat recovery in industry or downstream of other prime movers (e.g., marine applications). It is also an excellent source of information to understand the current challenges faced by the technology, stemming from a very competitive market and increasingly stringent environmental regulations.

The organizers of ORC 2023 hope that the reader finds this work as exciting as the attendees to the conference and, maybe, make the decision to join the 8th edition to the conference in 2025.