53rd AiCARR International Conference

12 - 13 - 14 march 2024
Fiera Milano, Rho (MI) | MCE 2024

From NZEB to ZEB: the buildings of the next decades for a healthy and sustainable future

AiCARR
Cultura e Tecnica per Energia Uomo e Ambiente

60 anni di cultura

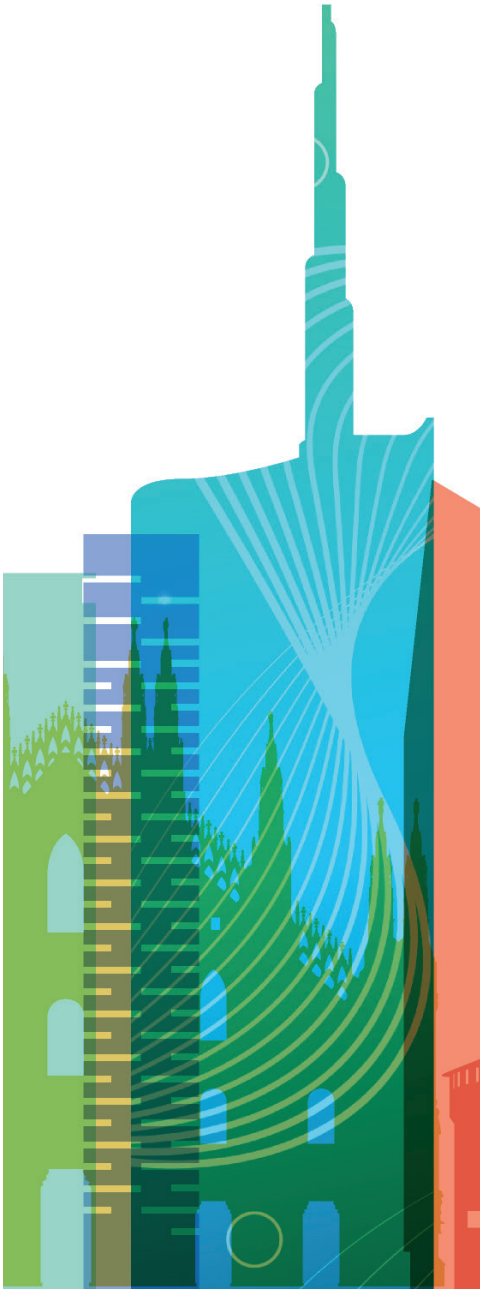
INDUSTRY MEMBERS

AiCARR
Cultura e Tecnica per Energia Uomo e Ambiente
anni di cultura

AiCARR
Via Melchiorre Gioia 168
20125 Milano MI
Tel. 02 67479270
Fax. 02 37928719
e-mail: info@aicarr.org
web site: www.aicarr.org
ISBN 9788895620794

Copyright AiCARR 2024. Tutti i diritti sono riservati. Nessuna parte del volume può essere riprodotta o diffusa senza il permesso scritto dell'Editore.
AiCARR declina ogni responsabilità diretta e indiretta per il contenuto degli articoli pubblicati nel presente volume.
Copyright AiCARR 2024. All rights are reserved. No part of the present volume can be reproduced or diffused with any means without written authorization of the Editor.
AiCARR cannot be deemed directly or indirectly responsible for the contents of the articles published in the present volume.

WELCOME TO THE 53RD AiCARR INTERNATIONAL CONFERENCE



The adopted revision of the European Energy Performance of Buildings Directive (EPBD) requires that by 2028 all newly-constructed buildings will be zero emission (ZEB, Zero Emission Building), and all existing buildings will have to become zero emissions by 2050. Such obligations will concern all residential and not-residential buildings (with some exceptions) and will provide for the achievement of challenging energy classes: residential buildings will have to reach class E by 2030 and class D by 2033; the other buildings, including those owned by public-bodies, class E from 2027 and class D from 2030. The directive requires the Member States to present national plans for the energy requalification of buildings, leaving 15% of the most energy-intensive ones in

CONFERENCE PARTNER

mce mostra convegno® expocomfort

12-15 Marzo/March 2024 | Fiera Milano

WELCOME TO THE 53RD AiCARR INTERNATIONAL CONFERENCE

the lowest energy class. According to Istat data, there are approximately 1.8 million residential buildings in Italy in class G out of a total of 12 million. The expected exemptions will be able to mitigate the impact of this obligation, but the effects of the directive will be really important in countries like Italy. Here a large part of the residential building stock was built before 1991 and the deep renovation of the older buildings would require significantly longer times than those expected at the European level, with higher costs.

At the same time, the increasing diffusion of renewable energy sources and the electrification of energy uses introduce urgent issues concerning the optimization of hybrid systems, the use of multi-source heat pump systems, different types of energy storage (including the use of new energy carriers such as hydrogen), in the context of an ever-increasing decarbonisation of buildings. In this context, it is suitable to investigate, through the contribution of wide-ranging analysis and more specialized studies, the opportunities provided by integrating technologies, systems, and building design in the transition from NZEB to ZEB, also considering a better internal environment quality. Based on these items, the 53rd AiCARR International Conference will present contributions of interest to the HVAC sector, relating to innovative design approaches, new monitoring and control systems, new components and systems, with related insights into their impact on energy consumption, comfort (thermal-hygrometric, acoustic, visual, air quality) and on the healthiness of internal environments.

ENDORSED BY

IEQ-GA

IIF IIR
INSTITUT INTERNATIONAL DU FROID
INTERNATIONAL INSTITUTE OF REFRIGERATION

REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations

SCIENTIFIC COMMITTEE

AiCARR President: Claudio Zilio
President Cultural Commission: Marco Noro, *Università degli Studi di Padova*

Francesco Asdrubali - Università degli Studi Roma 3
William Bahnfleth - Pennsylvania State University
Marco Beccali - Università degli Studi Di Palermo
Umberto Berardi - Politecnico di Bari
Nicola Bianco - Università degli Studi di Napoli Federico II
Livio De Santoli - Università La Sapienza Roma
Marco Dell'isola - Università degli Studi di Cassino e del Lazio Meridionale
Gianpiero Evola - Università degli Studi di Catania
Enrico Fabrizio - Politecnico di Torino
Giorgio Ficco - Università degli Studi di Cassino e del Lazio Meridionale
Andrea Frattolillo - Università degli Studi di Cagliari
Andrea Gasparella - UniversitàdDi Bolzano FRSE
Catalin Lungu - Presidente Rehva
Livio Mazzarella - Politecnico di Milano
Luca Molinaroli - Politecnico di Milano
Gian Luca Morini - Università degli Studi di Bologna
Alessandro Prada - Università degli Studi di Trento
Fabio Sciurpi - Università degli Studi di Firenze
Fabio Serpilli - Università Politecnica delle Marche
Timothy Wentz – Università del Nebraska
Angelo Zarrella - Università degli Studi di Padova

ORGANIZING COMMITTEE

Coordinatore: Luca Alberto Piterà – *AiCARR General Secretary*
Roberto Taddia - Milano, Como, Lodi, Monza e Brianza, Pavia, Varese, *Territorial Delegate*
Stefania Bracco – *AiCARR Board*
Matteo Dongellini - *AiCARR Cultural Commission*
Gennaro Loperfido – *AiCARR Board*
Fabio Minchio – *AiCARR Board*
Federico Pedranzini – *AiCARR Board*
Mara Portoso – *AiCARR Board* Gabriella Lichinchi - *AiCARR Secretariat*

INTRODUCTION

The adopted revision of the European Energy Performance of Buildings Directive (EPBD) requires that by 2028 all newly-constructed buildings will be zero emission (ZEB, Zero Emission Building), and all existing buildings will have to become zero emissions by 2050. Such obligations will concern all residential and not-residential buildings (with some exceptions) and will provide for the achievement of challenging energy classes: residential buildings will have to reach class E by 2030 and class D by 2033; the other buildings, including those owned by public bodies, class E from 2027 and class D from 2030.

The directive requires the Member States to present national plans for the energy requalification of buildings, leaving 15% of the most energy-intensive ones in the lowest energy class. According to Istat data, there are approximately 1.8 million residential buildings in Italy in class G out of a total of 12 million.

The expected exemptions will be able to mitigate the impact of this obligation, but the effects of the directive will be really important in countries like Italy. Here a large part of the residential building stock was built before 1991 and the deep renovation of the older buildings would require significantly longer times than those expected at the European level, with higher costs.

At the same time, the increasing diffusion of renewable energy sources and the electrification of energy uses introduce urgent issues concerning the optimization of hybrid systems, the use of multi-source heat pump systems, different types of energy storage (including the use of new energy carriers such as hydrogen), in the context of an ever-increasing decarbonisation of buildings.

In this context, it is suitable to investigate, through the contribution of wide-ranging analysis and more specialized studies, the opportunities provided by integrating technologies, systems, and building design in the transition from NZEB to ZEB, also considering a better internal environment quality.

Based on these items, the 53rd AiCARR International Conference will present contributions of interest to the HVAC sector, relating to innovative design approaches, new monitoring and control systems, new components and systems, with related insights into their impact on energy consumption, comfort (thermal-hygrometric, acoustic, visual, air quality) and on the healthiness of internal environments.

INDEX

OPENING SESSION – KEYNOTE

DECARBONIZING DISTRICT ENERGY SYSTEMS: THE US PERSPECTIVE 001
Ellis Blake, *ASHRAE Fellow, LEED AP, Principal, Burns & McDonnell—ASHRAE Task Force for Building Decarbonization Executive Committee*

RECENT ADVANCEMENTS IN THERMAL ENERGY STORAGE FOR HVAC 029
Mancin Simone, *University of Padova*

SESSION 1 – INNOVATION IN BUILDINGS COMPONENTS AND TECHNOLOGIES SESSION

KEYNOTE 047
FROM NZEB TO ZEB: THE ROLE OF BUILDINGS SIMULATION
Gasparella Andrea, *Free University of Bozen*

FROM SINGLE TESTS TO A TEST-CHAIN: A COMPREHENSIVE APPROACH FOR EVALUATING THE INTERACTION BETWEEN THE BUILDING ENVELOPE AND THE IEQ 061
Babich Francesco, Pinotti Riccardo, Gazzin Riccardo, Visentin Chiara, Lollini Roberto, *Eurac Research, Bolzano; Italy*

THE IMPACT OF PLACEMENT-RELATED EFFECTS IN AIR-COOLED COOLING CHILLERS ON ENERGY EFFICIENCY 077
Kavas Süleyman, Özel Burak, *Cowriter, Ankara, Turkey*

EVALUATING THE IAQ AND ENERGY PERFORMANCES OF VENTILATION SYSTEMS IN MULTIFAMILY BUILDINGS 093
Kiani Zohreh, Nour Eddine Alì, *Eurovent Certita Certification, Paris, France*
Taurines Kévin, Cordeiro Mendonça Kátia, Tipee *Plateforme Technologique du Bâtiment Durable, Lagord, France*
Abadie Marc Olivier, *La Rochelle Université, La rochelle, France*

TOWARDS ZERO ENERGY BUILDINGS: THE UNIZEB CASE STUDY 111
Carnieletto Laura, *Università Ca' Foscari, Venezia, Italy*
Mitrovic Milica, Riccardi Beatrice, Turrini Umberto, Bignucolo Fabio, De Carli Michele, *Università degli Studi di Padova, Italy*

SCENARIOS FOR THE ENERGY RENOVATION OF A RESIDENTIAL BUILDING 127
Malevolti Guglielmo, Rocchetti Andrea, Socci Luca, *Università degli Studi di Firenze, Italy*

SIMULATION OF THE ENERGY PERFORMANCE OF BUILDING ARCHETYPES ACCORDING TO ITALIAN REGULATIONS, WITH THE IDENTIFICATION OF UPGRADING SOLUTIONS BASED ON COST-BENEFIT ANALYSIS IN RELATION TO CLIMATE CHANGE 149
Carletti Cristina, Cellai Gianfranco, Sciurpi Fabio, *Università di Firenze, taly*
Pierangioli Leone, *Libero Professionista, Firenze, Italy*
Riccomi Alessio, *Libero Professionista, Montecatini Terme, PT, Italy*

RETROFITTING HISTORICAL BUILDINGS WITH INNOVATIVE TECHNIQUES: DOUBLE-SKIN FACADE AND SKYLIGHTS FOR COURTYARD BUILDINGS 167
Aruta Giuseppe, Ascione Fabrizio, Bianco Nicola, Iaccheo Anna, Iovane Teresa, Mastellone Margherita, *Università degli Studi di Napoli Federico II*

EN-SOLEX": A NOVEL SOLAR EXOSKELETON FOR THE ENERGY-EFFICIENCY RETROFITTING OF EXISTING BUILDINGS 183
Stasi Roberto, Ruggiero Francesco*, Politecnico di Bari, Italy*
Berardi Umberto, *Toronto Metropolitan University, Canada*

SESSION 2 – INTEGRATION OF CONTROL AND BUILDING AUTOMATION SYSTEMS

ARTIFICIAL INTELLIGENCE-BASED ALGORITHMS APPLIED TO HVAC SYSTEMS FOR THE OPTIMAL CONTROL IN BUILDINGS 199
Bernardello Filippo, Astolfi Giacomo, Alessio Giulia, Andreoli Michele, Lovato Riccardo, Nicastro Alessandra, *Alperia Green Future Srl, Bolzano, Italy*

ENERGY, ECONOMIC AND ENVIRONMENTAL BENEFITS OF DEMAND RESPONSE FOR IMPROVING BUILDING ENERGY FLEXIBILITY 213
Dal Cin Enrico, *Università degli Studi di Padova, Italy*
Rech Sergio, *Centro studi di economia e tecnica dell'energia Giorgio Levi Cases, Università degli studi di Padova, Italy*
Benetti Marianna, *Veil Energy Srl Società Benefit, Bolzano, Italy*

A DATA-DRIVEN MODEL FOR THE ANALYSIS OF ENERGY CONSUMPTION IN BUILDINGS 227
Borgato Nicola, Zarrella Angelo, Prataviera Enrico, Bordignon Sara, *Università di Padova, Italy*
Garay - Martinez Roberto, *Universidad de Deusto, Spain*

ENERGETIC ADVANTAGES AND WELLBEING IMPROVEMENT FOR BUILDINGS OCCUPANTS, CONNECTED TO DYNAMIC BUILDING ENVELOP SOLUTIONS, WITH SPECIAL FOCUS ON INTELLIGENT SOLAR SHADING AND VENTILATIVE COOLING OF NZEB AND ZEB BUILDINGS 243
Gandini Jacques, *Studio Gandini, Verona, Italy*

TOWARDS SUSTAINABLE INDOOR ENVIRONMENT: OPTIMIZING NZEB AND ZEB THROUGH ADVANCED VENTILATION STRATEGIES 259
Pagan Andrea, Simonetti Raul, Di Dia Davide, Poppi Alessandro, *CAREL Industries s.p.a, Padova, Italy*

GOVERN COMPLEX SYSTEMS IN THE DESIGN OF AN INNOVATIVE, SAFE AND SUSTAINABLE HOSPITAL 273
Prete Daniele, Elia Gianluca, *Università del Salento, Lecce, Italy*
Piscitelli Prisco, *Local Health Authority ASL Lecce, Italy, Italian Society of Environmental Medicine (SIMA), Milan, Italy*

A NOVEL TOOL TO DETECT ABNORMAL THERMAL ENERGY CONSUMPTIONS IN BUILDINGS EQUIPPED WITH LIMITED METERING INFRASTRUCTURE 289
Canale Laura, Ficco Giorgio, Dell'Isola Marco, *Università degli Studi di Cassino e del Lazio Meridionale, Cassino, Italy*
Di Pietra Biagio, Puglisi Giovanni, Bertini Ilaria, *ENEA, Palermo, Italy*

ONE-YEAR OPERATION PERFORMANCES OF A DECENTRALISED ALL-AIR HVAC SYSTEM FOR A SCHOOL ROOM 313
Noro Marco, *Università degli Studi di Padova, Italy*
Busato Filippo, *Universitas Mercatorum, Roma, Italy*
Piterà Luca Alberto, *AiCARR, Milano, Italy*

A PILOT PROJECT FOR ENERGY RETROFIT OF EDUCATIONAL BUILDINGS -THE ENGINEERING CAMPUS OF THE UNIVERSITY OF L'AQUILA 329
De Rubeis Tullio, De Berardinis Pierluigi, *Department of Civil, Construction-Architectural and Environmental Engineering University of .L'Aquila*
Smarra Francesco, Franchi Fabio, D'Innocenzo Alessandro, *Department of Information Engineering, Computer Science and Mathematics, University of L'Aquila*
Di Battista Davide, Ambrosini Dario, *Department of Industrial and Information Engineering and Economics, University of L'Aquila*

SESSION 3 - INNOVATION IN PLANTS COMPONENTS AND TECHNOLOGIES

EXPERIMENTAL ASSESSMENT OF A 18 KWH LATENT THERMAL ENERGY STORAGE COUPLED WITH A HEAT PUMP FOR RESIDENTIAL AIR CONDITIONING 343
Righetti Giulia, Mancin Simone, *Università di Padova, Italy*
Campidelli Matteo, Bottaro Oreste, *Innova Engineering srl, Trento, Italy*
Feo Domenico, *Sunservice srl, Castelfranco Veneto, Treviso; Italy*

ASSESSMENT OF THE ENERGY PERFORMANCE OF A SOLAR/BIOMASS HYBRID SYSTEM FOR THE CLIMATIZATION OF SMALL- AND MEDIUM-SCALE BUILDINGS 357
Dongellini Matteo, Naldi Claudia, Morini Gian Luca, *Alma Mater Studiorum - Università di Bologna, Italy*
Moser Christoph, *Institute of Thermal Engineering, Graz University of Technology, Graz, Austria*
Varga Szabolcs, Soares João, *Institute of Science and Innovation in Mechanical and Industrial Engineering, Porto, Portugal*

DESIGN OPTIMIZATION FOR ENERGY EFFICIENCY IN HEAT PUMPS WITH REFRIGERANT R-454C 373
Codella Fabrizio, *Chemours Italy, Agrate Brianza, Italy*
Küpper Hans-Dieter, *Chemours Deutschland, Neu-Isenburg, Germany*

M-CYCLE BASED SUB-WET BULB ADIABATIC COOLING SYSTEMS: AN OVERVIEW OF THE TECHNOLOGY AND POSSIBLE APPLICATIONS FOR THE ITALIAN CLIMATES 385
Peli Samuele, Belli Luca, *Seeley International, Arezzo, Italy*

ELITURBO AIR-MIXER: CFD MODELLING OF A TECHNOLOGY FOR THE REDUCTION OF THERMAL STRATIFICATION IN LARGE SPACES 401
Polito Antonio, *Libero Professionista*, *Castelfranco Veneto TV, Italy*
Mistè Gianluigi, De Betta Stefano, *NablaWave srl Padova, Italy*
Campolmi Paolo, *Impresind srl, Gorgonzola, Milano, Italy*

TECHNICAL-ECONOMIC AND FINANCIAL FEASIBILITY OF NEW TECHNOLOGIES IN THE ENERGY REFURBISHMENT OF RESIDENTIAL BUILDINGS 415
Paduos Simona, Chiappero Marco, Iunco Alberto, Romano Roberto, *C2R Energy Consulting, Torino, Italy*
Corrado Vincenzo, Santarelli Massimo, *Politecnico di Torino, Italy*

POTENTIAL OF ENERGY SAVING OF PROPANE HEAT PUMP AS REPLACEMENT OF GAS BOILERS WITH LOW AND HIGH TEMPERATURE EMITTERS 431
Morini Gian Luca, Camponeschi Corrado, Goni Maurizio, Cioffi Francesca, Dongellini Matteo, Naldi Claudia, *Alma Mater Studiorum, University of Bologna, Italy*
Germano Luca, Genovese Filippo, Cervellati Andrea, Casolari Alessandro, *GALLETTI s.p.a., Bentivoglio, Bologna, Italy*
Corsaro Federico, Ciancamerla Matteo, Ballotta Luca, *DANFOSS srl, Torino, Italy*

EMERGING TECHNOLOGIES FOR AIR CLEANING AND THEIR INTEGRATION IN HVAC SYSTEMS: WHICH ROLE IN THE INCREASING QUEST FOR HEALTHY AND SUSTAINABLE BUILDINGS? 447
Joppolo Cesare Maria, *Politecnico di Milano, Italy*
Gandini Jacques, *Studio Gandini, Verona, Italy*

EPBD 2023, F-GAS 2024, ECO-DESIGN AND SAFETY STANDARDS: WHICH DESIGN MARGINS TO BE COMPLIANT WITH? AT WHAT COST? 465
Ascione Fabrizio, De Rossi Filippo, Iovane Teresa, Mastrullo Rita, Mauro Alfonso William, Palella Francesco *Università degli Studi di Napoli Federico II, Italy*

SESSION 4 - REGULATIONS AND LEGISLATION

PROPER DEFINITIONS AND COMPARABLE TEST METHODS FOR NEW HEATERS TO TACKLE THE CHALLENGE OF A SUSTAINABLE DECARBONISATION OF EXISTING RESIDENTIAL BUILDINGS 481
Zambrelli Cristian, D'Acunti Valentina, Tomasi Roberta, Bronzoni Cristiana, *Immergas, Brescello, Reggio Emilia, Italy*

THE ENERGY RENOVATION PATHWAY TO ZEB IN ITALY: ANALYSIS OF TYPICAL BUILDINGS AND METHODOLOGICAL ASPECTS 497
Di Turi Silvia, Ronchetti Laura, Sannino Raniero, Calabrese Nicolandrea, Iatauro Domenico, *ENEA, Roma, Italy*

ENHANCING SUSTAINABILITY IN CONSTRUCTION: ANALYSIS OF HIGH-EFFICIENCY SOLUTIONS FOR NZEBS IN THE MARCHE REGION 515
Serpilli Fabio, Di Perna Costanzo, Lori Valter, *Università Politecnica delle Marche, Ancona, Italy*
Di Loreto Samantha, *Università "D'Annunzio", Chieti-Pescara, Italy*

ENERGY PERFORMANCE AND THERMAL COMFORT ASSESSMENT OF AN EDUCATIONAL BUILDING IN NORTHERN ITALY: THE IMPORTANCE OF CLIMATIC FILES IN ENERGY SIMULATIONS 529
Serpilli Fabio, *Università Politecnica delle Marche, Ancona, Italy*
Lops Camilla, Montelpare Sergio, Pierantozzi Mariano, *Università "D'Annunzio", Chieti-Pescara, Italy*

THE IMPACT OF THE NEW EPBD "GREEN HOUSES" IN THE ITALIAN BUILDING CONTEXT: TECHNICAL-ECONOMIC ANALYSIS ON IMPROVING THE ENERGY CLASS OF EXISTING BUILDINGS 543
D'Agostino Diana, Minelli Federico, Minichiello Francesco, *Università degli Studi di Napoli Federico II, Italy*
Russo Nicola, *Ingegnere libero professionista, Napoli, Italy*

ANALYSIS OF THE PHYSICAL PHENOMENA AND MODELLING PROCEDURES OF BUILDING HEATING AND COOLING EMISSION SYSTEM ENERGY LOSSES 559
Bianco Mauthe Degerfeld Franz, Ballarini Ilaria, Corrado Vincenzo, *Politecnico di Torino, Italy*

CO_2 EMISSION REDUCTION, LOADS ANALYSIS, AND STRATEGIES FOR NEW HEALTHCARE FACILITIES DESIGN – APPLICATION ON A CASE STUDY 575
Mantua Francesco, Bo Elena, Turco Margherita, *Prodim srl, Torino, Italy*
Ferrara Maria, *Politecnico di Torino, Italy*
Rossi Prodi Fabrizio*, Rossi Prodi Associati srl, Firenze, Italy*

EVOLUTION OF ENERGY DIAGNOSES AND ENERGY MANAGEMENT SYSTEMS: REGULATIONS, TOOLS AND PROFESSIONALS SERVING ENERGY EFFICIENCY 591
La Mura Sergio, *Studio Ingegneria La Mura, Milano, Italy*
Piterà Luca Alberto, *AiCARR, Milano, Italy*

READINESS OF ZERO-EMISSION BUILDINGS (ZEBS) IMPLEMENTATION IN EUROPEAN UNION 607
Maduta Carmen, D'Agostino Delia, *Joint Research Centre, European Commission, Ispra (VA), Italy*

SESSION 5 - BUILDINGS IN AN URBAN SCALE

MIXED-USE NEIGHBOURHOOD TO MAXIMISE URBAN ENERGY COMMUNITY POTENTIAL 617
Vecchi Francesca, *Politecnico di Bari, Italy*
Berardi Umberto*, Toronto Metropolitan University, Canada*

SHALLOW GEOTHERMAL SYSTEMS IN DENSE URBAN AREAS: THE ISSUE OF THERMAL INTERFERENCE AND LONG-TERM SUSTAINABILITY 633
Angelotti Adriana, Sterpi Donatella, *Politecnico di Milano, Italy*

ZERO EMISSION BUILDINGS IN URBAN AREAS 649
Filippi Marco, *Politecnico di Torino, Italy*
Sirombo Elisa, *GET srl, Torino, Italy*

ENERGY AND ECONOMIC SIMULATION OF A RENEWABLE ENERGY COMMUNITY APPLIED TO A NEW GENERATION ULTRA-LOW TEMPERATURE DISTRICT HEATING AND COOLING NETWORK 665
Romagnosi Michela, Aprile Marcello, Denariè Alice, *Politecnico di Milano, Italy*

GEOTHERMAL DISTRICT HEATING: ENERGY, ENVIRONMENTAL AND ECONOMIC ANALYSIS OF A CASE STUDY IN NORTHERN ITALY 681
Di Nunzio Nicola, Angelotti Adriana, Denariè Alice, *Politecnico di Milano, Italy*

DYNAMIC EVALUATION OF THE ELECTRICAL PRIMARY ENERGY FACTOR FOR BUILDING ENERGY PERFORMANCE: INSIGHTS FROM 2022 ITALIAN DATA 697
Oldini Riccardo, Bilardo Matteo, Fabrizio Enrico, *Politecnico di Torino, Italy*

DECARBONISING THE BUILT ENVIRONMENT WITHIN A WHOLE-LIFE CYCLE PERSPECTIVE 711
Maiorano Teodoro, Borello Davide, Sirombo Elisa, *GET srl, Torino, Italy*

VIRTUAL ENERGY SHARING AND ENERGY COMMUNITIES FOR THE MUNICIPALITY OF MILAN: STRATEGY AND TECHNICAL ANALYSES. THE CASE OF THE CHIARAVALLE AREA 727
Causone Francesco, Ferroni Sibilla, *Politecnico di Milano, Italy*
Minchio Fabio, *Studio 3F Engineering, Creazzo (VI), Italy*
Sordi Giuseppina, Giuliani Iliaria, Cremascoli Elena, Paci Christina, *Comune di Milano, Italy*

EXPLOITING GEOGRAPHIC OPEN DATA TO IMPROVE URBAN BUILDING ENERGY SIMULATIONS: THE PADOVA CITY CENTER CASE STUDY 747
Khajedehi Mohamad, Prataviera Enrico, Bordignon Sara, De Carli Michele, *University of Padova, Italy*

SESSION 6 - INTERACTION BETWEEN PEOPLE AND BUILDINGS

NEW GENERATION ENERGY PERFORMANCE CERTIFICATE: DEVELOPMENT AND APPLICATION IN AN ITALIAN CASE STUDY AS AN EU PROOF OF CONCEPT 763
Salvalai Graziano, Isacco Ilaria, *Politecnico di Milano, Italy*
Sesana Marta Maria, *Università degli studi di Brescia, Italy*

CROSS-MODAL EFFECTS OF INDOOR AIR QUALITY AND ACOUSTIC CONDITIONS IN CLASSROOMS ON STUDENTS' COMFORT AND PERFORMANCE 779
Pellegatti Matteo, *Università degli studi di Ferrara, Eurac Research, Ferrara, Bolzano, Italy*
Prodi Nicola, *Università degli studi di Ferrara*
Visentin Chiara, *Università degli studi di Ferrrara, Italy*
Torresin Simone, *Università di Trento, Italy*
Babich Francesco*, Eurac Research, Bolzano, Italy*

UVC-MIRROR FOR EFFECTIVE PATHOGENS INACTIVATION IN AIR DUCTS 791
Treccani Laura, Rovetta Daniele, *CSMT Innovative Contamination Hub, Brescia, Italy*
Gobbi Emanuela*, Università degli Studi di Brescia, Italy*
Turina Massimo, *Istituto per la Protezione Sostenibile delle Piante (IPSP), CNR, Torino, Italy*
Lombini Matteo, Cortecchia Fausto, Diolaiti Emiliano, Malaguti Giuseppe, *INAF - Osservatorio di Astrofisica e Scienza dello Spazio, Bologna, Italy*
Bianco Andrea, Pareschi Giovanni, *Istituto Nazionale di Astrofisica - Osservatorio Astronomico di Brera, Merate (Lc), Italy*
Mongelluzzo Giuseppe, *INAF - Osservatorio Astronomico di Capodimonte, Napoli, Italy*
Lessio Luigi, *INAF- Osservatorio Astronomico di Padova, Italy*

LIQUID AIR FILTRATION AND CONTINUOUS MONITORING: CUSTOMIZED IAQ 807
Capulli Domenico, Regazzi Rogerio, *Veltha Air pollution Control, Rio de Janeiro, Brazil*

ASSESSMENT OF INDOOR ENVIRONMENTAL COMFORT IN A RECENTLY RENOVATED OFFICE BUILDING IN MESSINA CITY 823
Savoca Ludovica Maria Sofia, *Università degli Studi di Messina, Italy*

ANALYSIS OF THE RELEVANT TECHNICAL CHARACTERISTICS IN INDOOR COMFORT TERMINAL UNITS FOR THE PURPOSE OF SATISFYING THE DEMANDING ENERGY, FUNCTIONAL, HYGIENIC AND SUSTAINABILITY REQUIREMENTS OF NZEB AND ZEB BUILDINGS 839
Gandini Jacques, *Studio Gandini srl, Verona, Italy*

THERMAL COMFORT MONITORING IN OFFICE BUILDINGS: A CASE STUDY 859
Sannino Raniero, Iatauro Domenico, Lavinia Carmen, Nardi Iole, *ENEA, Roma, Italy*

ENHANCING INDOOR AIR QUALITY IN OFFICE BUILDINGS: INSIGHTS FROM A FIELD STUDY 875
Torriani Giulia, *Institute for Renewable Energy, Eurac Research, Department of Civil Environmental and Mechanical Engineering, University of Trento, Bolzano – Trento, Italy*
Lara-Ibeas Irene, Babich Francesco, *Institue for Renewable Energy, Eurac Research, Bolzano, Italy*

TOWARDS ENVIRONMENTAL SUSTAINABILITY OF NON-RESIDENTIAL BUILDINGS: AN INTEGRATED APPROACH TO COMBINE THERMAL COMFORT OF PEOPLE WITH ENERGY SAVING STRATEGIES FOR HEATING SYSTEM MANAGEMENT 891
Proietti Maria Giulia, Elefante Marco, Moretti Elisa, *Università degli Studi di Perugia, Italy*
Proietti Luca, Longhi Francesco, *ARPA Umbria, Terni, Italy*

CASCINA OREMO: A RENOVATION OF A BUILDING FOR PEOPLE WITH DISABILITIES, WHERE WE ALL LEARN TO ACHIEVE EFFICIENCY TOGETHER 907
Riva Gabriele, *Favero Engineering, Milano, Italy*
Magri Massimiliano, Catone Marco*, Coster Group, Milano, Italy*

New generation Energy Performance Certificate: development and application in an Italian case study as an EU proof of concept

GRAZIANO SALVALAI[1] – MARTA MARIA SESANA[2] – ILARIA ISACCO[1]

[1] *Department of Architecture, Built Environment and Construction Engineering (ABC), Politecnico di Milano, Milan, IT*
[2] *Department of Civil, Environmental, Architectural Engineering and Mathematics (DICATAM), University of Brescia, Brescia, IT*

SUMMARY

The latest Energy Performance of Buildings Directive (EPBD) recast, adopted on March 2023, focuses on the revision of the Energy Performance Certificate (EPC) (art. 16) with the introduction of new indicators to boost the EPC implementation and use as a clearer, more reliable, and easy-to-understand tool in line with the Green Deal's climate neutrality goals, providing a dedicated template in the Annex V. In this context, the H2020 Energy Performance Certificate Recast (EPC RECAST) project aims to develop a process for the implementation and validation of such a new generation of EPC, with a focus on existing residential buildings. The paper presents the state of progress of the EPC RECAST testing methodology, comparing its research procedure with the standard national ones, currently in use in the different project countries to validate the approach regarding reliability and user-friendliness. The core of the paper is the presentation of the research methodology, specifying each step of the testing approach for assessing the new generation of EPC to highlight the challenges and potentialities of the procedure, coupled with its application in an Italian case study as a Proof of Concept (PoC). The work highlights on the one hand the applicability and user-friendly method developed by the project for the new generation EPCs in line with the EPBD and on the other hand the limits and potentialities of EPC improvement as a key tool towards the decarbonization of the building sector.

Keywords: Energy Performance Certificate, New generation, Testing approach, Case study

1. INTRODUCTION

Decarbonization is one of the main objectives for the global energy transition and Europe is on the frontline, having set - with the Green New Deal - the goal of zero net emissions of Greenhouse Gases (GHG) by 2050 (European Commission, 2019). Currently, buildings' construction and operation are responsible for 40% of the energy consumption and 36% of the energy-related greenhouse gas emissions in the European context. Moreover, 75% of EU buildings are not energy efficient. Therefore, energy retrofit is of primary

importance to cut energy needs and tackle energy poverty, helping people reduce energy use and energy bills.

In December 2023, at the COP28 UN Climate Change Conference in Dubai, a set of actions was identified to accelerate the path, including an agreement to transition away from fossil fuels and to reduce global emissions by 43% by 2030. Focusing on the construction sector, a dedicated initiative, the so-called Buildings Breakthrough has been defined under the Breakthrough Agenda, to strengthen international collaboration to decarbonize the building sector and make clean technologies and sustainable solutions the most affordable, accessible, and attractive option in all regions by 2030.

To address the decarbonization of the European building stock, the revised Energy Performance of Buildings Directive (EPBD) promotes buildings' efficiency and renovation through several actions: (i) set Minimum Energy Performance Standards to upgrade the worst-performing 16% of the EU building stock from energy label G to at least energy label F by 2030 and the 26% to at least energy label E by 2033, (ii) require an Energy Performance Certificate (EPC) for all public buildings, for buildings undergoing major renovation and for the ones for which a rental contract is renewed, (iii) set charging infrastructure for electric vehicles in both residential and non-residential buildings, (iv) require an EPC for all buildings which are offered for sale or rent and state the energy label in all advertisement, (v) include in National Building Renovation Plans roadmaps for phasing out fossil fuels in heating and cooling by 2040 and stop financial incentives for the installation of systems powered by fossil fuels, (vi) provide a Building Renovation Passport to facilitate users' access to information and lower costs through a step-by-step renovation process, (vii) include renovation considerations in public and private financing rules and establish instruments to help low-income households (European Commission, 2023).

By placing more value on the EPC, the latest EPBD recast (European Commission, 2021a), paves the way for a new generation of EPCs, characterized by the implementation of a common template with a defined set of indicators presented in Annex V "Template for energy performance certificates". Most of the recommended indicators are related to energy efficiency (e.g., the energy performance class, the calculated annual primary energy use, and consumption, the calculated annual final energy use and consumption, the renewable energy production on-site and the share of renewable energy out of the energy use), while the decarbonization issue is addressed through the indication of the operational greenhouse gas emissions and of the greenhouse gas emission class. Annex V reports also some suggested indicators related to plant systems characterization, including renewable energy production and storage systems, building's envelope characterization, pollution due to the building's operation, indoor thermal comfort and air quality, sustainable mobility and metered energy consumption. Moreover, the new generation EPC should include, when present, a link to the smart readiness assessment of the building and the Digital Building Logbook. Besides the EPC's indicators, the latest EPBD promotes another important aspect to increase the potentialities of this tool: a user-centric approach for EPC comprehension and assessment. Making the final user (e.g., household, tenant) a central figure in the decarbonization path of the building stock, would become a win-win solution to boost the implementation of a common and user-friendliness language within a new generation of EPC, with clear and easy-to-understand indicators. Moreover, as stated in Art. 16, the certificate will be issued by independent experts after an on-site visit, thus ensuring its reliability and

affordability. In this way, the new generation EPC will represent a key tool to support energy retrofit and trigger new investments in the building sector's efficiency.

In this context, the H2020 Energy Performance Certificate Recast (EPC RECAST) project is part of a cluster of 12 other Horizon 2020 projects (QualDeEPC, U-CERT, X-tendo, D^2EPC, E-DYCE, ePANACEA, crossCert, EUB SuperHub, iBRoad2EPC, TIMEPAC, CHRONICLE, SmartLivingEPC), started between 2019 and 2022, which work in continuous cooperation to enhance the development of new generation EPCs, through non-disclosed expert workshops to discuss outcomes and share knowledge, as well as, open events where all the projects are presented together to send a stronger message to all the stakeholders. Among them, the EPC RECAST project aims to develop a well-structured process and a toolbox to support the implementation and validation (Salvalai et al. 2021) of a new generation of EPCs, with a focus on existing residential buildings, for which retrofit is one of the most challenging and pressing issues. It involves 11 partners composing a multidisciplinary consortium, ranging from the research activity (e.g., CSTB, Tecnalia, Fraunhofer-Gesellschaft, Luxembourg Institute of Science and Technology, Politecnico di Milano) to industrial activity (e.g., EDF, ENGIE, BIMEO, ENBEE, R2M Solution) and international associations (e.g., REHVA).

To verify the compliance of the overall methodology in terms of user-friendliness and reliability of the calculation results (Salvalai, et al. 2022), the project has framed a testing approach on selected case studies (i.e., buildings and dwellings from the different consortium partner countries). The state of progress of the methodological framework is described in section 2, followed by the application of the method to an Italian case study as a proof of concept of the overall approach in section 3. Afterward, the main results in terms of the applicability of the methodology and potentialities for improvement are highlighted and reported in the conclusions.

2. METHODOLOGY

The EPC RECAST testing method aims to assess both a valid national EPC, through the standard procedure currently in use in each country, and a new generation one, using the procedure developed in the project, benchmarking then the new process and output with the current ones. It is based on four main steps (Figure 1): (i) site inspection preparation, (ii) on-site data collection, (iii) in-office modeling and calibration, (iv) EPC and Renovation Roadmap creation and delivery.

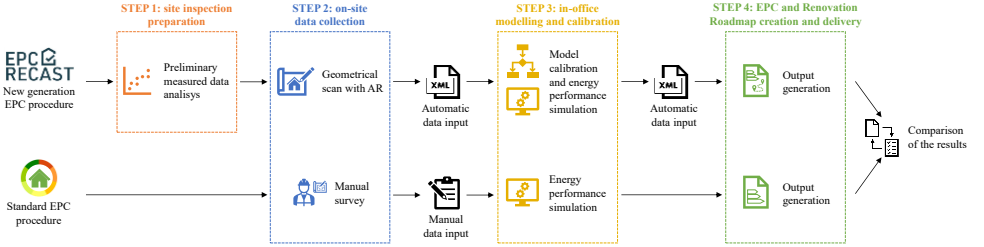


Figure 1 – EPC RECAST testing method. Authors' elaboration.

It involves actors with different levels of knowledge and familiarity with the energy performance assessment and certificates, namely the EPC RECAST case study responsible, who performs the new procedure, the EPC assessor, who performs the standard procedure, and the building or dwelling owner.

The active involvement of these different actors responds to the strong importance given to the user centric approach by the overall project methodology to deliver a clear, consistent and effective new generation EPC for both experts (e.g., EPC assessors, building energy auditors, engineering or construction companies and operators in charge of building refurbishment and/or renovation) and non-experts (e.g., building owners, dwellers and occupants, policymakers in charge of new legal recommendations' proposals on building renovation and refurbishment or revisions of the EPBD and other EU policies, banks and insurances needing consistent data for granting loans upon request).

The "site inspection preparation" is the first step of EPC RECAST testing method, which aims at preparing all the preliminary documents and analysis necessary for the application of the new energy performance assessment procedure. The EPC RECAST case study responsible oversees this phase, during which an overall presentation of the project is performed to the EPC and the building or dwelling owner. At the same time, the case study responsible and the assessor co-define the common input data necessary for the energy consumption calculation, coupled with a preliminary analysis of the measured data collected for the case study and related to: indoor and outdoor climate conditions (i.e., temperature and humidity), indoor air quality and energy consumption.

The second step, the so-called "on-site data collection" involves both the case study responsible, who explains to the assessor and the owner how the visit will be carried out and then collects the case study geometrical data through an Augmented Reality scanning procedure and the EPC assessor, who collect the case study geometrical data through the standard national procedure currently in use in the respective EU country. During the audit usually, the EPC RECAST responsible presents to the case study owner also how the new generation EPC and Renovation Roadmap look like to better explain the key differences between the two EPC versions, the added value concerning the standard national EPC, but also to collect feedback to further improve the procedure.

The "in-office modeling and calibration" step involves both the case study responsible and the EPC assessor. In this phase they perform the energy simulation following, respectively, the new approach based on automatic conversion of collected data into the calculation engine and the standard approach based on the national calculation tool. Moreover, for some specific case studies, the EPC RECAST case study responsible calibrates the numerical model using the energy consumption measured data collected for the specific building or dwelling.

The fourth step is the "EPC and Renovation Roadmap creation and delivery", it is dedicated to the final output development, and it involves the case study responsible, the EPC assessor, and the case study owner. At this point of the procedure, the assessor completes the standard national EPC, while the EPC RECAST case study responsible completes the new generation EPC and finally compares their respective outputs results through the Quantitative Verification Strategy, explained more in detail in the following section.

2.1. The Quantitative Verification Strategy

The Quantitative Verification Strategy is procedure defined within the EPC RECAST project to verify the effective improvement of the EPC RECAST calculation process for the building energy consumption assessment. It is based on eight different Evaluation Strategies, namely an energy consumption comparison between the elements of the new generation EPC and the standard one in terms of climatic and building use conditions, input data collection method, calculation method, and output generation process. One of the comparisons focuses on the benchmark between the calculated energy consumption values and the measured ones, obtained by the Long-Term Monitoring (LTM) campaign on the specific case study, to assess the reliability of the EPC RECAST data through the overall procedure from collection and modeling to the final data assessment of the EPC new generation.

In particular, the case studies selected for the monitoring have been equipped with several LoRaWAN sensors for collecting long-term data. LoRaWAN is the protocol that runs "on top of" the LoRa (short for Long Range) modulation which manages the network connectivity. In other words, LoRa is a new and emerging wireless standard and LoRaWAN is the wireless sensors that provide ultra-long range to industry standard gateways. The data collected are concerning actual energy consumption and indoor conditions and they will be used in energy model calibration for further assessing the reliability of the EPC RECAST approach.

Figure 2 graphically represents the elements considered within the Evaluation Strategies clustered by three main areas: 1) climatic and building use conditions, 2) data collection, 3) calculation tool.

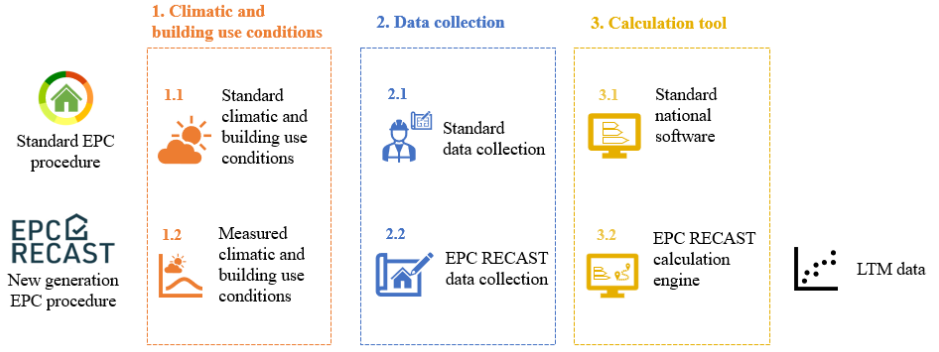


Figure 2 – EPC RECAST Evaluation Strategies elements. Authors elaboration.

For the first area, the elements considered for the standard EPC and the new generation one are respectively: 1.1) standard climatic and building use conditions, namely the weather data and the standard occupancy profiles reported in the national regulations for the energy consumption calculation in residential buildings or the weather file recorded by the national weather stations and 1.2) measured climatic and building use conditions, represented by the outdoor temperature and humidity data obtained through LTM and by the occupancy profiles extrapolated from the measured indoor temperature and energy consumption data. For the second area: 2.1) standard data collection, namely the national

procedure currently in use in each country for collecting input data about the building or dwelling geometry, envelope and plant systems' characteristics, 2.2) EPC RECAST data collection, carried out using an Augmented Reality geometrical scan which directly collects in the building or dwelling 3D model all the information about the envelope and plant systems' characteristics. Finally for the third area: 3.1) standard national software, namely the calculation tool currently in use in each country for the energy consumption assessment and 3.2) the EPC RECAST calculation engine, based on an online interface automatically filled in through the XML file generated by the scanning tool.

Combining the elements described above, each Evaluation Strategy allows to compare the reliability and effectiveness of a specific phase of the EPC RECAST testing method, as well as of the whole process, from a technical and quantitative point of view. The first Evaluation Strategy, presented in Figure 3, compares the energy consumption calculated through the new generation procedure, apart from model calibration, with the energy consumption measured through the LTM campaign. Its objective is to evaluate the reliability of the EPC RECAST process when it involves a non-calibrated numerical model.

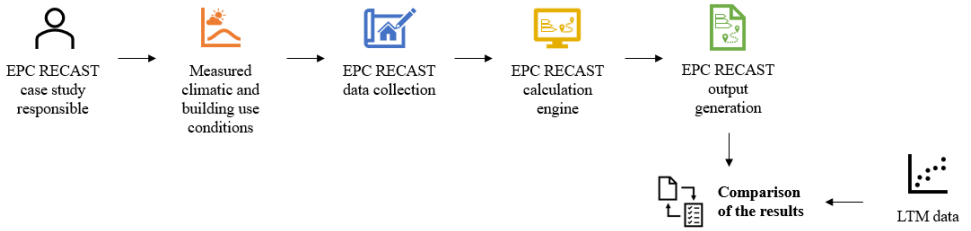


Figure 3 – Scheme of Evaluation Strategy no.1. Authors elaboration.

The second Evaluation Strategy allows instead the comparison between the energy consumption calculated through the whole new generation procedure, including the model calibration, and the energy consumption measured through the LTM campaign. Its objective is to assess the impact of using a calibrated numerical model.

The third Evaluation Strategy compares the energy consumption calculated through the new generation procedure with the energy consumption calculated through the new generation procedure combined with the standard data collection. Moreover, this Evaluation Strategy benchmarks the results of the two calculations with the energy consumption measured through the LTM campaign. Its objective is the assessment of the EPC RECAST data collection's impact.

The fourth Evaluation Strategy allows the comparison between the energy consumption calculated through the new generation procedure and the energy consumption calculated through the standard national procedure. Its objective is to evaluate the reliability of the EPC RECAST process.

The fifth Evaluation Strategy compares the energy consumption calculated through the standard national procedure with the energy consumption calculated through the new generation procedure combined with the standard national software. Its objective is the impact assessment of the EPC RECAST data collection within the standard national procedure for issuing an Energy Performance Certificate.

The sixth Evaluation Strategy compares the energy consumption calculated through the new generation procedure and the energy consumption calculated through the standard national procedure combined with the EPC RECAST calculation engine. Its objective is to assess the impact of EPC RECAST data collection within the new generation procedure.

The seventh Evaluation Strategy compares the energy consumption calculated through the standard national procedure with the energy consumption calculated through the new generation procedure combined with the standard data collection. Its objective is to evaluate the reliability of the EPC RECAST process when the data are collected through the standard method currently in use in each country.

Finally, the eighth Evaluation Strategy, graphically summarized in Figure 4, allows the comparison between the energy consumption calculated through the new generation procedure and the energy consumption calculated through the standard national procedure combined with the EPC RECAST data collection. Its objective is to evaluate the reliability of the EPC RECAST calculation engine when the data are collected through the new generation method proposed within the project.

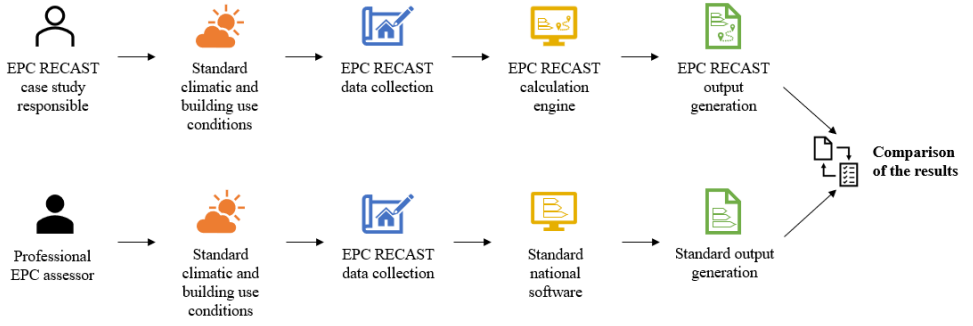


Figure 4 – Scheme of Evaluation Strategy no.8. Authors' elaboration.

The application of the Evaluation Strategies in each case study has been a milestone for the proof of concept of the overall EPC RECAST approach and case by case one of the eight strategies has been selected depending on its specific characteristics and the preliminary data analysis on the measured data.

3. CASE STUDIES FOR THE APPLICATION OF THE TESTING APPROACH

The applicability of the methodology developed has been one of the main important goals to reach since the definition of the project, for this reason, the testing approach, described in the previous section, has been applied to several case studies in 6 EU countries corresponding to the EPC RECAST consortium partner countries (France, Germany, Italy, Luxembourg, Slovakia and Spain). In some cases, for each recruited building there is only one dwelling, while in some other cases, there is more than one, so the EPC RECAST testing approach will be applied to a total of 81 dwellings, corresponding to a total of 57 buildings. Figure 5 presents the distribution of the case studies in the six EU countries and

highlights the number of dwellings where Long-Term Monitoring is undergoing. The different case studies have been selected to be representative of the European building stock in terms of construction types and materials, building typologies, energy performance, heating and DHW systems, energy carriers, climate conditions, etc. To analyze a wide variety of the above-mentioned technical features, the case studies have been selected among buildings or dwellings constructed in different periods from 1900 to today and subjected to different levels of renovation actions.

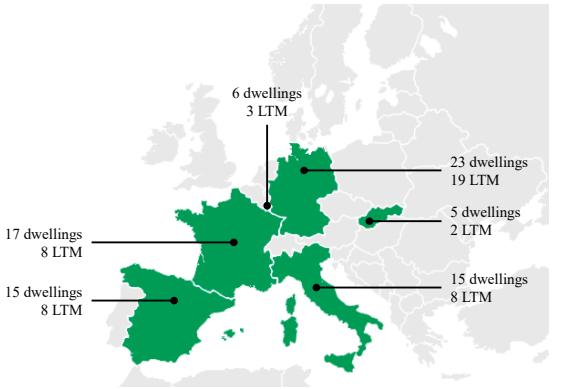


Figure 5 – Number of dwellings per consortium partner country. Authors elaboration.

In the following subsection the current state of progress about the application of the testing approach to an Italian case study is presented.

3.1. Application of the methodology in a real case study

The case study described in this section has the goal to show and discuss the status of the validation testing approach on a residential building in Italy.

Specifically, the selected case study is an apartment in a multifamily building built in 2008 located in Lombardy Region. It is a three-room flat on the last floor of the building, composed of a living room with a kitchen, two bedrooms, and a bathroom (Figure 6) and with a habitable surface of 66 m^2 (165 m^3 of volume). Moreover, the property is completed by a private terrace onto which all the rooms' windows open.

Figure 6 – Italian case study: façade view and plan. Authors' elaboration.

The building has a traditional reinforced concrete structure for pillars and beams, while the envelope is realized with different layers. The external walls are made of bricks, completed with polystyrene insulation and plaster coating on the outside and with rockwool insulation and plasterboard on the inside. The roof is instead composed by wood boards, with polystyrene insulation and metallic sheet finishing. Finally, the floor is made of an insulated concrete slab. To complete the envelope, double glazing windows with aluminum frame are installed everywhere. As regards the plant systems, the apartment is heated and cooled with a radiant floor powered by a centralized gas boiler in the winter season and by a centralized electrical cooling system in summer. Moreover, the flat is equipped with a single flux centralized mechanical ventilation system, while the DHW is produced by a centralized gas boiler and solar panel collectors.

The case study is part of the buildings and dwellings selected for the Long-Term Monitoring campaign, therefore, according to its plant systems' characteristics, the following set of sensors has been installed for collecting data about the climatic conditions and the energy vectors for heating, cooling, DHW and electricity: (i) an optical pulse sensor on the electrical meter for reading the hourly consumption, (ii) ultrasonic flow meters for DHW and heating mass flow detection, (iii) temperature sensors for measuring DHW and heating inlet and outlet water temperature, (iv) temperature and humidity sensors for measuring the indoor and outdoor climatic conditions. All the collected data are sent via router to the EPC RECAST monitoring platform through a dedicated LoRaWan network. In addition to the installed sensors, the energy and water consumption of the case study are also monitored through the smart meter already present in the dwelling. For both the monitoring solutions, the data have been collected for more than one year, from February 2022 to November 2023.

The first step of the testing method (site inspection preparation) includes the preliminary analysis of the measured data collected through the Long-Term Monitoring campaign. The indoor and outdoor climatic conditions, registered by the installed sensors with an hourly timestep, allow to understand the relationship between the energy consumption for heating and cooling and the indoor-outdoor temperature difference. Therefore, besides the temperature/humidity over time graph presented in Figure 7, a more detailed analysis has been carried out calculating the mean indoor and outdoor temperatures registered during the heating period, defined by DPR 412/1993 (Italian Republic, 1993) from 15th October to 15th April for Lecco (climate zone E) and during the cooling period, set from the end of May to the end of September based on experience.

As regards the energy consumption, the measured data for thermal energy has been collected through the smart meter and therefore the values corresponding to heating, cooling and DHW can be read separately. Presenting the consumptions both for thermal and electrical energy, Figure 8 highlights a small difference between the energy consumption for heating and cooling, while the highest amount of energy is used for lighting, cooking, and appliances. In the context of EPC RECAST project, the measured data presented above allows to make a realistic correlation between the energy simulation of the apartment and what happens in real conditions. In particular, the outdoor climatic conditions are useful to understand the influence of the case study's specific location and of its surroundings on the standard simulation conditions currently in use in Italy, while the indoor temperature and

humidity data allows to analyze the real condition of building use set by the occupants. Finally, the measured data referred to the energy consumption will be used at the end of the testing approach to verify the effective reliability of the EPC RECAST methodology.

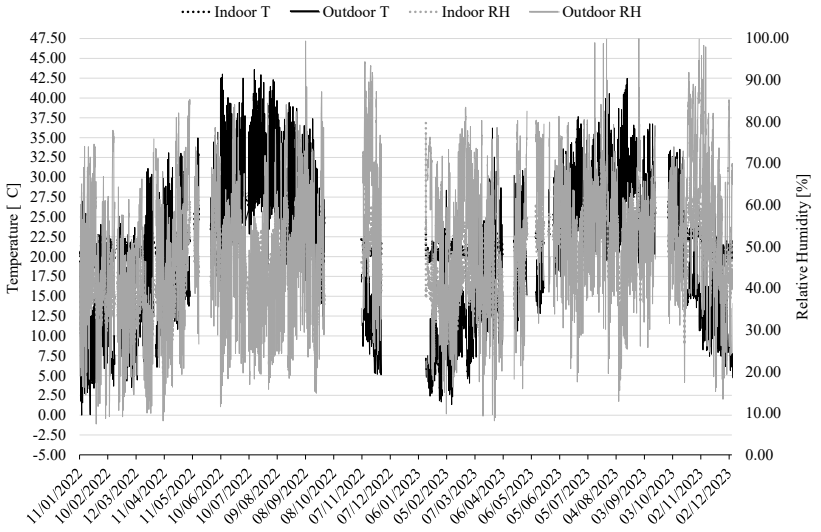


Figure 7 – Italian case study, temperature/humidity over time graph. The heating period indoor and outdoor mean temperatures are respectively equal to 21.26 °C and 12.63 °C, while the cooling period indoor and outdoor mean temperatures are respectively equal to 26.76 °C and 26.55 °C. Authors elaboration.

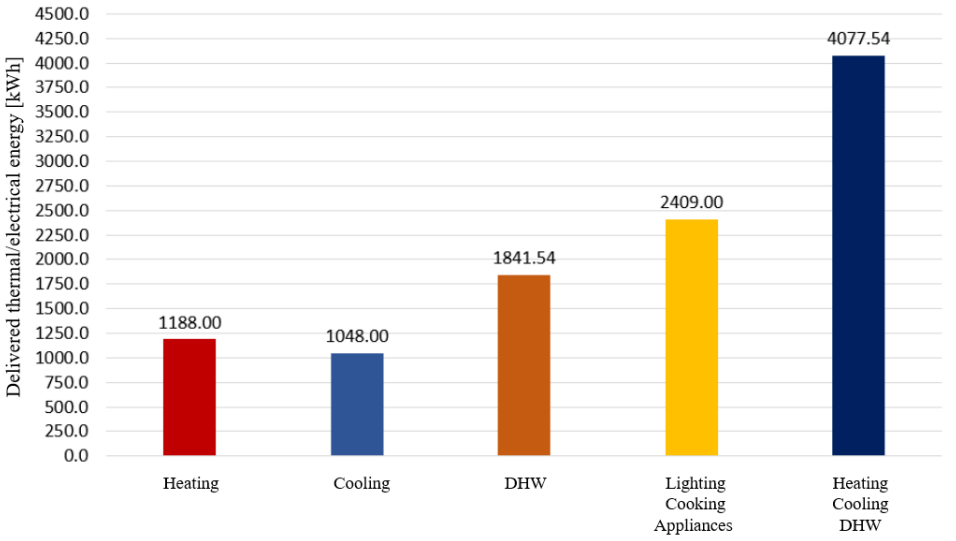


Figure 8 – Italian case study, thermal and electrical energy consumption measured between February 2022 and November 2023. Authors elaboration.

During the second step of the testing method (on-site data collection), the case study responsible collected the apartment geometrical data through the augmented reality scanner (Figure 9) provided by the partner BIMEO, which allowed a fast survey of each room element (e.g., walls, floor, ceiling, windows, and doors).

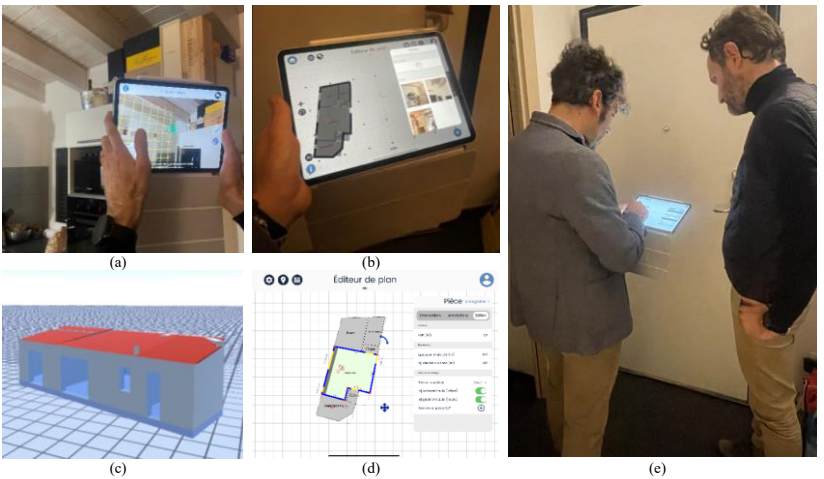
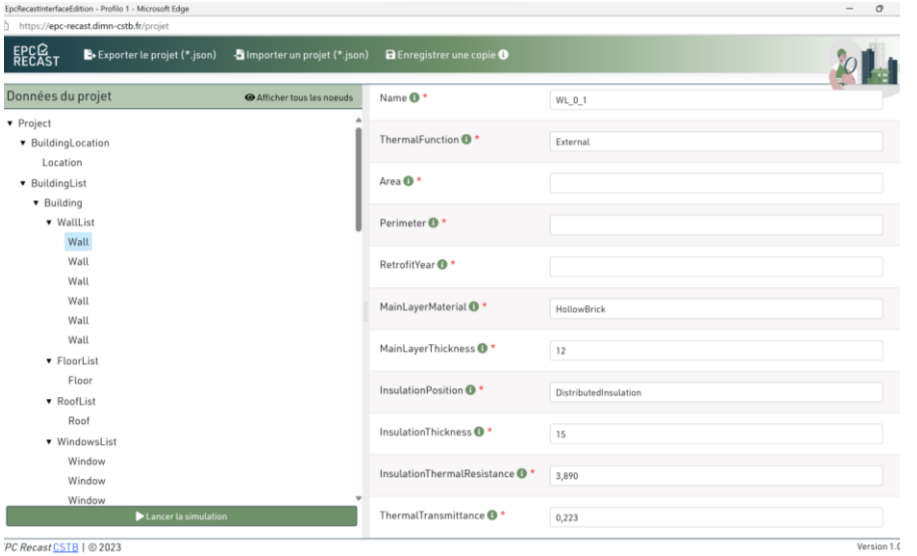


Figure 9 – Italian case study, on-site data collection using BIMEO app, (a) room scanning, (b) 2D geometrical model of the apartment, (c) 3D geometrical model of the apartment, (d) information automatically collected through the scanning of a room, (e) EPC RECAST case study responsible showing the scanning tool to the EPC assessor. Authors elaboration.

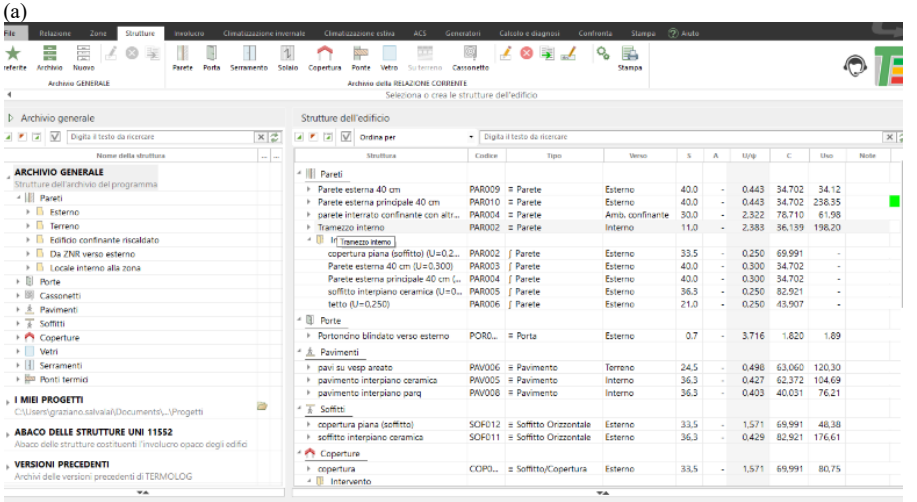
Figure 10 – Italian case study, geometrical model enrichment, (a) information automatically collected through the scanning of a wall, (b) wall's questionnaire. Authors' elaboration.

In parallel to the EPC RECAST data collection procedure by the BIMEO app, the EPC assessor performs the geometrical survey through the standard national procedure

currently in use in Italy, which is commonly done using a tape measure or laser meter and manually collecting additional information from the owner about building materials, thermal properties, and plant systems characteristics.
The enriched geometrical data collected on-site by the case study responsible, and the information collected by the EPC assessor, have then been used as input for the respective calculation tools (Figure 11).



(a)



(b)

Figure 11 – Italian case study, calculation tools, (a) EPC RECAST online interface, (b) standard national calculation tool (TERMOLOG by Logical Soft). Authors' elaboration.

The EPC RECAST process automatically generates an XML file of the data collected on-site which has been imported into the calculation engine. This tool is structured as an online interface in which the case study responsible can check all the data and eventually add/modify some information, keeping in mind that the unknown values are calculated as mean values from related standards/regulations. In the current practice, the EPC assessor needs, instead, to proceed with a manual sketch-based survey and build the model using a standard national calculation tool, where it manually adds all the technical information collected during the on-site inspection.

Referring to the Figure 1, the current state of validation of the EPC RECAST testing method has completed Step 1 and Step 2. The following steps foresee the data mining of the inputs collected in Step 2 to model and calibrate the results, which will become inputs for the Renovation Roadmap development and the assessment through the Quantitative Verification Strategy of Step 4.

CONCLUSIONS

The present work provides an overview of the research activities of the EPC RECAST project related to the development of the new generation EPC, with a focus on the testing and verification phase of the developed approach through its application in real case studies. The specific case study described in the paper allows to assess both the applicability of the testing approach at its current state of progress and the limits and potentialities for improvement of EPCs as key tools towards the decarbonization of the building sector. Two out of four steps of the developed methodology have been applied and validated. The collection of Long-Term Monitoring data through the IoT sensors in fact has proved to be affordable in terms of costs and at the same time reliable in terms of data quality and amount of storable information and the data collection tool proved its rapidity and adequate precision in scanning rooms of different dimensions and complexity. Moreover, the potentiality of the questionnaires and the georeferenced photos for the geometrical data enrichment avoids the loss of information, which is recorded by professionals as a very common barrier in the current practice. The complete validation of the methodology will be the subject of future publications once the two remaining steps will be applied and verified.

Regarding the improvement of EPCs, the state of progress of the EPC RECAST testing approach identifies the monitoring of real conditions (such as weather and internal set point and use conditions) as a critical element, not considered in the current Italian certification schemes, but potentially able to increase the reliability of the building's energy assessment as well as the reliability of the certificate from the user's perspective, providing an easy-to-understand parameter directly related to the operational costs faced by the occupants.

REFERENCES

CHRONICLE: Building Performance Digitalisation and Dynamic Logbooks for Future Value-Driven Services (2022-2025), Grant Agreement (GA) No: 101069722, last accessed: December 2023, https://www.chronicle-project.eu/

crossCert: Cross Assessment of Energy Certificates in Europe (2021-2024), Grant Agreement (GA) No: 101033778, last accessed: December 2023, https://www.crosscert.eu/

D^2EPC: Next-generation Dynamic Digital EPCs for Enhanced Quality and User Awareness (2020-2023), Grant Agreement (GA) No: 892984, last accessed: December 2023, https://www.d2epc.eu/en

E-DYCE: Energy flexible DYnamic building CErtification (2020-2023), Grant Agreement (GA) No: 893945, last accessed: December 2023, https://edyce.eu/

ePANACEA: Smart European Energy Performance AssessmeNt And CErtificAtion (2020-2023), Grant Agreement (GA) No: 892421, last accessed: December 2023, https://epanacea.eu/

EPC RECAST: Energy Performance Certificate Recast (2020-2024), Grant Agreement (GA) No: 893118, last accessed: December 2023, https://epc-recast.eu/

Salvalai, G.; Sesana, M.M. Long-Term Monitoring Strategies for Increasing EPCs Reliability. *Environ. Sci. Proc.* 2021, *11*, 16. https://doi.org/10.3390/environsciproc2021011016

Salvalai, G.; Sesana, M.M. Monitoring Approaches for New-Generation Energy Performance Certificates in Residential Buildings. *Buildings* 2022, *12*, 469. https://doi.org/10.3390/buildings12040469

EUB SuperHub: European Building Sustainability performance and energy certification Hub (2021-2024), Grant Agreement (GA) No: 101033916, last accessed: December 2023, https://eubsuperhub.eu/

European Commission. 2021a. Annexes to the Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast). COM(2021) 802 final.

European Commission. 2023. Commission welcomes political agreement on new rules to boost energy performance of buildings across the EU. European Commission - Press release.

European Commission. 2019. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal. COM(2019) 640 final.

European Commission. 2021b. Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast). COM(2021) 802 final.

Italian Republic. 1993. Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'Art. 4, Comma 4, della Legge 9 gennaio 1991, n. 10. DPR 26 agosto 1993, n. 412 (G. U. n.96 del 14/10/1993).

iBRoad2EPC: Integrating Building Renovation Passports into Energy Performance Certification schemes for a decarbonised building stock (2021-2024), Grant Agreement (GA) No: 101033781, last accessed: December 2023, https://ibroad2epc.eu/

QualDeEPC: High-quality Energy Performance Assessment and Certification in Europe Accelerating Deep Energy Renovation (2019-2023), Grant Agreement (GA) No: 847100, last accessed: December 2023, https://qualdeepc.eu/

SmartLivingEPC: Advanced Energy Performance Assessment towards Smart Living in Building and District Level (2022-2025), Grant Agreement (GA) No: 101069639, last accessed: December 2023, https://www.smartlivingepc.eu/en/

TIMEPAC: Towards innovative methods for energy performance assessment and certification of buildings (2021-2024), Grant Agreement (GA) No: 101033819, last accessed: December 2023, https://timepac.eu/

U-CERT: Towards a new generation of user-centered Energy Performance Assessment and Certification; facilitated and empowered by the EPB Center (2019-2023), Grant Agreement (GA) No: 839937, last accessed: December 2023, https://u-certproject.eu/

X-tendo: eXTENDing the energy performance assessment and certification schemes via a mOdular approach (2019-2022), Grant Agreement (GA) No: 845958, last accessed: December 2023, https://x-tendo.eu/

ACKNOLEDGEMENTS

The present work has been developed within the EPC RECAST - "*Energy Performance Certificate Recast*" project, which has received funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement number 893118.

AUTHOR INDEX

Abadie M. O. 093
Alessio G. 199
Ambrosini D. 329
Andreoli M. 199
Angelotti A. 633, 681
Aprile M. 665
Aruta G. 167
Ascione F. 167, 465
Astolfi G. 199
Babich F. 061, 779, 875
Ballarini I. 559
Ballotta L. 431
Belli L. 385
Benetti M. 213
Berardi U. 183, 617
Bernardello F. 199
Bertini I. 289
Bianco A. 791
Bianco M.D. F. 559
Bianco N. 167
Bignucolo F. 111
Bilardo M. 697
Bo E. 575
Bordignon S. 227, 747
Borello D. 711
Borgato N. 227
Bottaro O. 434
Bronzoni C. 481
Busato F. 313
Calabrese N. 497
Campidelli M. 343
Campolmi P. 401
Camponeschi C. 431
Canale L. 289
Capulli D. 807
Carletti C. 149
Carnieletto L. 111
Casolari A. 431
Catone M. 907
Causone F. 727
Cellai G. 149
Cervellati A. 431
Chiappero M. 415
Ciancamerla M. 431
Cioffi F. 431
Codella F. 373
Cordeiro Mendonça K. 093
Corrado V. 415, 559
Corsaro F. 431
Cortecchia F. 791
Cremascoli E. 727
D'Acunti V. 481
D'Agostino D. 543, 607
D'Innocenzo A. 329
Dal Cin E. 213
De Berardinis P. 329
De Betta S. 401
De Carli M. 111, 747
De Rossi F. 465
De Rubeis T. 329
Dell'Isola M. 289
Denariè A. 665, 681
Di Battista D. 329
Di Dia D. 259
Di Loreto S. 515
Di Nunzio N. 681

Di Perna C. 515
Di Pietra B. 289
Di Turi S. 497
Diolaiti E. 791
Dongellini M. 357, 431
Elefante M. 891
Elia G. 273
Ellis B. 001
Fabrizio E. 697
Feo D. 343
Ferrara M. 575
Ferroni S. 727
Ficco G. 289
Filippi M. 649
Franchi F. 329
Gandini J. 243, 447,839
Garay-Martinez R. 227
Gasparella A. 047
Gazzin R. 061
Genovese F. 431
Germano L. 431
Giuliani I. 727
Gobbi E. 791
Goni M. 431
Iaccheo A. 167
Iatauro D. 497, 859
Iovane T. 167, 465
Isacco I. 763
Iunco A. 415
Joppolo C. M. 447
Kavas S. 077
Khajedehi M. 747
Kiani Z. 093
Küpper H. D. 373
La Mura S. 591
Lara-Ibeas I. 875
Lavinia C. 859
Lessio L. 791
Lollini R. 061
Lombini M. 791
Longhi F. 891
Lops C. 529
Lori V. 515
Lovato R. 199
Maduta C. 607
Magri M. 907
Maiorano T. 711
Malaguti G. 791
Malevolti G. 127
Mancin S. 029, 343
Mantua F. 575
Mastellone M. 167
Mastrullo R. 465
Mauro A. W. 465
Minchio F. 727
Minelli F. 543
Minichiello F. 543
Mistè G. 401
Mitrovic M. 111
Mongelluzzo G. 791
Montelpare S. 529
Moretti E. 891
Morini G. L. 357, 431
Moser C. 357
Naldi C. 357, 431
Nardi I. 859
Nicastro A. 199
Noro M. 313
Nour Eddine A. 093
Oldini R. 697
Özel B. 077
Paci C. 727

Paduos S. 415
Pagan A. 259
Palella F. 465
Pareschi G. 791
Peli S. 385
Pellegatti M. 779
Pierangioli L. 149
Pierantozzi M. 529
Pinotti R. 061
Piscitelli P. 273
Piterà L. A. 313, 591
Polito A. 401
Poppi A. 259
Prataviera E. 227, 747
Prete D. 273
Prodi N. 779
Proietti L. 891
Proietti M. G. 891
Puglisi G. 289
Rech S. 213
Regazzi R. 807
Riccardi B. 111
Riccomi A. 149
Righetti G. 343
Riva G. 907
Rocchetti A. 127
Romagnosi M. 665
Romano R. 415
Ronchetti L. 497
Rossi Prodi F. 575
Rovetta D. 791
Ruggiero F. 183
Russo N. 543
Salvalai G. 763
Sannino R. 497, 859
Santarelli M. 415
Savoca L. M. S. 823
Sciurpi F. 149
Serpilli F. 515, 529
Sesana M. M. 763
Simonetti R. 259
Sirombo E. 649, 711
Smarra F. 329
Soares J. 357
Socci L. 127
Sordi G. 727
Stasi R. 183
Sterpi D. 633
Taurines K. 093
Tomasi R. 481
Torresin S. 779
Torriani G. 875
Treccani L. 791
Turco M. 575
Turina M. 791
Turrini U. 111
Varga S. 357
Vecchi F. 617
Visentin C. 061, 779
Zambrelli C. 481
Zarrella A. 227