First International Conference on Building Integrated Renewable Energy Systems
Conference organized in collaboration with COST Action TU 1205-BISTS

6th- 9th March 2017
Dublin Institute of Technology (DIT) Ireland
DIT Grangegorman

BIRES 2017 - PROCEEDINGS

Edited by: Soteris A. Kalogirou and David Kennedy

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Framework Program Horizon 2020

COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Conference organized in collaboration

with COST Action TU1205

COST BSTS

Conference Themes

Building Integration of:

- Solar thermal systems (STS)
- Photovoltaic / Thermal (PV/T)
- Thermal Storage (TS)
- Hybrid systems (HS)
- Renewable and Sustainable Energy Systems

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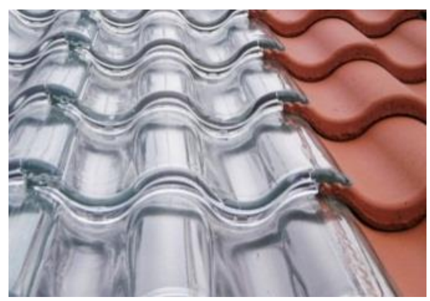

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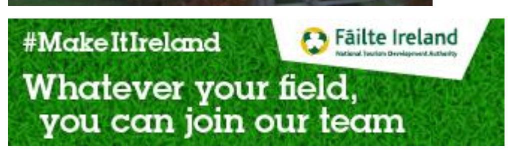
MEET IN IRELAND



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Book Edited by: Soteris A. Kalogirou, David Kennedy

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Programme
St. Laurence, DIT Grangegorman

Monday 6th March: Registration and Welcome Reception 6pm to 8pm.

POSTER SESSION
ART EXHIBITION environmental matrix view
(Prof. Yiannis Tripanagnostopoulos)

Tuesday 7th March:

Registration 8.30am - 9am. St. Laurence, DIT Grangegorman
Tuesday 7th March 9am-9.20am.: Opening Address by:
Professor Brian Norton, President DIT and Conference Chair and
Professor Soteris Kalogirou, Chair of COST Action TU1205

Tuesday 7th March: 9.20am to 11am. Paper Presentations: Session 1.(5 papers)
Tuesday 7th March: 11.20am to 12.50pm. Paper Presentations: Session 2.(5 papers)
Tuesday 7th March: 2pm to 3.30pm. Paper Presentations: Session 3.(6 papers)
Tuesday 7th March: 3.45pm to 5.30pm. Paper Presentations: Session 4.(5 papers)
POSTER SESSION & ENERGY in ART EXHIBITION
(Prof. Yiannis Tripanagnostopoulos)

Wednesday 8th March:

Registration 8.30am - 9am. St. Laurence, DIT Grangegorman
Wednesday 8th March: 9.00am to 11.am. Paper Presentations: Session 5. (7 papers)
Wednesday 8th March: 11.20am to 12.50pm. Paper Presentations: Session 6. (5 papers)
Wednesday 8th March: 2.00pm to 3.30pm. Paper Presentations: Session 7. (6 papers)
Wednesday 8th March: 3.45pm to 5.30pm. Paper Presentations: Session 8. (5 papers)
POSTER SESSION & ENERGY in ART EXHIBITION
(Prof. Yiannis Tripanagnostopoulos)

Thursday 9th March:

Registration 8.30am - 9am. St. Laurence, DIT Grangegorman
Thursday 9th March: 9.00am to 11.am. Paper Presentations: Session 9. (7 papers)
Thursday 9th March: 11.20am to 12.50pm. Paper Presentations: Session 10. (5 papers)
Thursday 9th March: 2pm to3.30pm. H2020 Meeting
Thursday 9th March: 3.30pm. Close of Conference:
Prof. Brian Norton & Prof. Soteris Kalogirou

Note: **The Authors shown in the following list are the authors specified in the system on submission. The full list of the authors can be seen in the full papers.**

Tuesday 7th March Paper Session 1: St. Laurence's

Chairs: Prof. Soteris Kalogirou and Dr. Mervyn Smyth

Achievements of BFIRST EU funded project on BIPV technology (Paper 90)
1. Dr. Eduardo Roman - Tecnalia, Spain, Solar area, Energy and Environment division (TECNALIA)
2. Prof. Soteris Kalogirou - Cyprus University of Technology (CUT)
3. Dr. Maider Machado - Tecnalia Research and Innovation, Energy and Environment.

A Building Integrated Photovoltaic (BIPV) demonstration building in Belgium with new Fibre Reinforced Solar Technology PV modules: Analysis with Simulation and Monitoring data (Paper 92)
1. Dr. Rafaela Agathokleousa - Cyprus University of Technology, Limassol, Cyprus
2. Prof. Soteris Kalogiroua - Cyprus University of Technology, Limassol, Cyprus
3. Dr. Stephane Pierret - Optimal Computing, Mons, Belgium

Thermal testing of new photovoltaic (PV) modules for building integration, encapsulated with glass fibre reinforced composite materials and comparison with conventional Photovoltaic (Paper 91)
1. Prof. Soteris Kalogirou - Cyprus University of Technology, Limassol, Cyprus
2. Dr. Rafaela Agathokleousa - Cyprus University of Technology, Limassol, Cyprus

Evaluation of performance at experimental buildings and real demonstration sites in BFIRST project: Theoretical and practical aspects for BIPV monitoring system (Paper 25)
1. Dr. michele pellegrino - enea
2. Dr. Eduardo Roman - tecnalia
3. Dr. Stephane Pierret – optimal computing
4. Mr. Vangelis Mathas - Center for Renewable Energy Sources (CRES)
5. Prof. Soteris Kalogirou - Cyprus University of Technology (CUT)
6. Mr. Giovanni Flaminio - enea
7. Dr. Arturo Matano - enea
8. Dr. Martinez Asier - tecnalia
9. Dr. Anastasios Kyritsis - Center for Renewable Energy Sources (CRES)

Energy investigation on households with BIPV modules under Net Metering Scheme (Paper 23)
1. Dr. Anastasios Kyritsis - Center for Renewable Energy Sources (CRES)
2. Dr. Efstathios Tselepis - Center for Renewable Energy Sources (CRES)
3. Mr. Vangelis Mathas - Center for Renewable Energy Sources (CRES)
4. Mr. John Nikoletatos - Center for Renewable Energy Sources (CRES)
5. Ms. Rafaela Agathokleous - Cyprus University of Technology (CUT)
6. Prof. Soteris Kalogirou - Cyprus University of Technology (CUT)

Tuesday 7th March Paper Session 2: St. Laurence's

Chairs: Professor Cristofari Christian and Dr. Deb Mondol Jayanta (UK)

Building façade integrated solar thermal collectors for water heating: simulation model and case studies (Paper 09)
1. Dr. Annamaria Buonomano - University of Naples Federico II
2. Mr. Cesare Forzano - University of Naples Federico II
3. Prof. Soteris Kalogirou - Cyprus University of Technology
4. Mr. Charalambos Kyriakou - Cyprus University of Technology
5. Prof. Adolfo Palombo - University of Naples Federico II

A building integrated solar air heating thermal collector prototype: modelling, validation and case studies (Paper 06)
1. Dr. Annamaria Buonomano - University of Naples Federico II
2. Mr. Claudio Esposito - University of Naples Federico II
3. Prof. Soteris Kalogirou - Cyprus University of Technology
4. Mr. Aggelos Mosphiliotis - Cyprus University of Technology
5. Prof. Adolfo Palombo - University of Naples Federico II
6. Mr. Zacharias Symeou - Cyprus University of Technology

Exergetic and energy-economic analysis of a Building Integrated PhotoVoltaic and Thermal system (Paper 05)
1. Dr. Annamaria Buonomano - University of Naples Federico II
2. Prof. Francesco Calise - University of Naples Federico II
3. Prof. Adolfo Palombo - University of Naples Federico II
4. Ms. Maria Vicidomini - University of Naples Federico II

Technical and economic analysis of a micro photovoltaic/thermal system working in Polish climatic conditions (Paper 60)
1. Mr. Jarosław Bigorajski - Warsaw University of Technology
2. Prof. Dorota Chwieduk - Warsaw University of Technology

A novel approach towards investigating the performance of different PVT configurations integrated on test cells: an experimental approach (Paper 95)
1. Mr. Vivek Tomar - Centre for Energy Studies, Indian Institute of Technology (IIT) Delhi, New Delhi, India.
2. Prof. Brian Norton - Dublin Institute of Technology
3. Prof. G.n. Tiwari - Centre for Energy Studies, Indian Institute of Technology

Tuesday 7th March Paper Session 3: St. Laurence's

Chairs: Dr. Annamaria Buonomano and Prof. Andreas Savvides

Aesthetic aspects for building integrated solar and wind energy systems (Paper 89)
1. Prof. Yiannis Tripanagnostopoulos - Dept of Physics, Univ. of Patras, Patra

Integration aspects of solar energy systems to renovated buildings (Paper 88)
1. Mr. Georgios Trypanagnostopoulos - Univ. of Patras, Patra 26500, Greece
2. Mrs. Eleni Karantagli - University of Patras, Patra 26500, Greece
3. Mr. Athanasios Koskinas - Univ. of Patras, Patra 26500, Greece
4. Prof. Yiannis Tripanagnostopoulos – Univ. of Patras, Greece

Single-Axis Mechanisms with Limited Stroke for Tracking Solar Thermal Collectors and Photovoltaic Modules Integrated in Building Façades (Paper 87)
1.Prof. Mircea Neagoe - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania
2.Assoc Prof. Bogdan Burduhos - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania
3.Assoc Prof. Mihai Comsit - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania
4.Dr. Nadia Cretescu - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania

Trapeze solar-thermal collectors: implementation prerequisites and solutions (Paper 86)
1. Prof. Ion Visa - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania
2. Dr. Mihai Comsit - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania
3. Prof. Macedon MOLDOVAN - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania

Nearly Zero Energy Community – an affordable and feasible transition concept towards sustainable cities (Paper 85)
1. Prof. Ion Visa - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania
2. Dr. Anca Duta - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania

Application Possibilities of Building Integrated Solar Tile Collectors **(Paper 11)**
1. Dr. Istvan Fekete - Faculty of Mechanical Engineering and Automation, PA University
2. Prof. Istvan Farkas - Szent Istvan University, Godollo

Tuesday 7th March Paper Session 4: St. Laurence's

Chairs: Prof. Brian Norton and Prof. Dorota Chwieduk

Outdoor performance of a trapeze solar-thermal collector for facades integration **(Paper 84)**
1. Dr. Anca Duta -Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania
2. Prof. Ion Visa - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania
3. Prof. Macedon Moldovan - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania

Experimental evaluation of the efficiency of Photovoltaic / Thermal (PV/T) modules integrated in the built environment **(Paper 83)**
1. Prof. Macedon MOLDOVAN - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania
2. Prof. Ion Visa - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania
3. Dr. Anca Duta - Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania

The importance of the solar systems to achieve the nZEB level in the energy renovation of southern Europe's buildings **((Paper 82)**
1. Dr. Ricardo Mateus - University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal.
2. Dr. Sandra Monteiro da Silva - University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal.
3. Dr. Manuela Almeida - University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal.

Optimization of a Building Integrated Solar Thermal System with Seasonal Storage **(Paper 81)**
1. Dr. Georgios Martinopoulos - International Hellenic University/School of Science
2. Mr. C Antoniadis - International Hellenic University/School of Science and Technology, Thessaloniki, Greece

Integration of PV Modules into the Building Envelope in Aim to Achieve Energy and Environmental Benefits **(Paper 13)**
1. Prof. Aleksandra Krstic-Furundzic - Faculty of Architecture, University of Belgrade,
2. Dr. Budimir Sudimac - Faculty of Architecture, University of Belgrade,
3. Mrs. Andjela Dubljevic - Faculty of Architecture, University of Belgrade,

POSTER SESSION & ART EXHIBITION (Prof. Yiannis Tripanagnostopoulos)

Wednesday 8th March Paper Session 5: St. Laurence's

Chairs: Dr. Laura Aeleni and Dr. Ricardo Mateus

Environmental Impact and Economic Analysis of a LED Lighting Products **(Paper 80)**
1. Prof. Christopher J. Koroneos - University of Western Macedonia, Bakola and Salviera, 50100, Kozani
2. Dr. Eva Nanaki - University of Western Macedonia, Bakola and Salviera

Performance and stability of semitransparent OPVs for building integration: A benchmarking analysis **(Paper 78)**
1. Dr. Daniel Chemisana - 1Applied Physics Section of the Environmental Science, University of Lleida

A Review of New Materials Used for Building Integrated Systems **(Paper 77)**
1. Dr. Jasna Radulovic - Faculty of Engineering, University at Kragujevac, Serbia
2. Dr. Danijela Nikolic - Faculty of Engineering, University at Kragujevac, Serbia

3. Dr. Mirko Blagojevic - Faculty of Engineering, University of Kragujevac, Serbia
4. Dr. Ivan Miletic - Faculty of Engineering, University at Kragujevac, Serbia
5. Dr. Mina Vasković - Faculty of Engineering, University at Kragujevac, Serbia

Experimental and numerical analysis of overheating in test houses with PCM in Latvian climate conditions (Paper 76)
1. Mr. Janis Ratnieks - University of Latvia, Riga Technical university
2. Dr. Andris Jakovičs - University of Latvia, Riga Technical university
3. Dr. Staņislavs Gendelis - University of Latvia
4. Prof. Diāna Bajāre - Riga Technical University

A new approach on corrosion tests for building materials with PCM (Paper 74)
1. Prof. Halime Paksoy - Çukurova University, Chemistry Department, 01330, Adana, Turkey
2. Prof. Gulfeza Kardas - Chemistry Department, Cukurova University, Turkey
3. Dr. Kemal Cellat - Chemistry Department, Cukurova University, Turkey
4. Dr. fatih tezcan - Chemistry Department, Cukurova University, Turkey

Benchmarking of energy demand of domestic and small business buildings (Paper 73)
1. Prof. Luisa F. Cabeza - Universitat de Lleida, Edifici CREA, Pere de Cabrera s/n, 25001, Lleida
2. Dr. Julia Coma - Universitat de Lleida, Edifici CREA, Pere de Cabrera s/n, 25001, Lleida
3. Mr. Jose Miguel Maldonado - Universitat de Lleida, Edifici CREA, Pere de Cabrera s/n, 25001, Lleida, Spain
4. Dr. Alvaro De Gracia - Universitat Rovira i Virgili, Av. Paisos Catalans 26, 43007 Tarragona, Spain.
5. Mr. Toni Gimbernat - SINAGRO ENGINYERIA S.L.P, Av. Estudi General 7, Altell 5, 25001, Lleida, Spain
6. Mrs. Teresa Botargues - USERFEEDBACK PROGRAM SL, Sant Jaume Apòstol

Building-integrated photovoltaic/thermal (BIPVT) prototype: Environmental assessment focusing on material manufacturing (Paper 07)
1. Dr. Chrysovalantou Lamnatou - University of Lleida
2. Dr. Mervyn Smyth - Ulster University
3. Dr. Daniel Chemisana - University of Lleida

Wednesday 8th March Paper Session 6: St. Laurence's

Chairs: Prof. Soteris Kalogirou and Prof. Luis Braganca

Two active integrated storage systems: Double skin facade and active slab with PCM (Paper 72)
1. Prof. Luisa F. Cabeza - Universitat de Lleida, Edifici CREA, Pere de Cabrera s/n, 25001, Lleida
2. Dr. Lidia Navarro - Universitat de Lleida, Edifici CREA, Pere de Cabrera s/n, 25001, Lleida
3. Dr. Alvaro De Gracia - Universitat Rovira i Virgili, Av. Paisos Catalans 26, 43007

Innovative Pathways to Thermal Energy Storage (INPATH- TES) project (Paper 71)
1. Prof. Luisa F. Cabeza - University of Lleida
2. Dr. Gabriel Zsembinszki - Universitat de Lleida, Edifici CREA, Pere de Cabrera s/n, 25001, Lleida
3. Ms. Gundula Weber - Austria Institute of Technology

Financial return of Solar Thermal Heating with Seasonal Thermal Energy Storage - a Swedish case study (Paper 70)
1. Dr. Shane Colclough - University of Ulster
2. Dr. Philip Griffiths - University of Ulster
3. Prof. Neil Hewitt - University of Ulster, Newtownabbey, Co Antrim, Ireland

Power Quality Analysis using Harmonic Heating factor by Multiple Energy Efficient Appliances in Smart Building (Paper 68)
1. Mr. Chittesh Veni Chandran - Dublin Institute of Technology
2. Dr. Malabika Basu - Dublin Institute of Technology

3. Dr. Keith Sunderland - Dublin Institute of Technology

Investigation of Joule heating effect on Performance of PV modules based on equivalent Thermal-Electrical Model (Paper 67)
1. Ms. Houda Morchid - Dublin Institute of Technology
2. Prof. Michael Conlon - Dublin Institute of Technology

Wednesday 8th March Paper Session 7: St. Laurence's

Chairs: Prof. Rosita Norvaisiene and Prof. Gilles Notton

Performance Evaluation of the Senergy Polycarbonate and Asphalt Carbon Nano-Tube Solar Water Heating Collectors for Building Integration (Paper 65)
1. Mr. Adrian Pugsley - Ulster University
2. Dr. Aggelos Zacharopoulos - Ulster University
3. Dr. Mervyn Smyth - Ulster University
4. Dr. Jayanta Mondol - Ulster University

Investigation of the thermal performance of a Concentrating PV/Thermal Glazing Façade Technology (Paper 64)
1. Dr. Aggelos Zacharopoulos - Ulster University
2. Dr. Jayanta Mondol – Ulster University
3. Dr. Mervyn Smyth - Ulster University
4. Dr. Trevor Hyde - Ulster University
5. Mr. Adrian Pugsley - Ulster University

Reactive power control for smarter (urban) distribution network management with increasing integration of renewable prosumers (Paper 59)
1. Mr. Arsalan H Zaidi - Dublin Institute of Technology
2. Dr. Keith Sunderland - Dublin Institute of Technology
3. Dr. Massimiliano Coppo - University of Padova
4. Prof. Michael Conlon - Dublin Institute of Technology
5. Dr. Roberto Turri - University of Padova

Double skin façades integrating photovoltaics and active shadings: a case study for different climates (Paper 10)
1. Prof. Andreas Athienitis - Concordia University
2. Dr. Annamaria Buonomano – Concordia University, University of Naples Federico II
3. Mr. Zissis Ioannidis - Concordia University
4. Dr. Konstantinos Kapsis - Concordia University
5. Prof. Ted Stathopoulos - Concordia University

Experimental performance comparison of a Hybrid Photovoltaic/Solar Thermal (HyPV/T) Façade Module with a flat ICSSWH module (Paper 56)
1. Dr. Mervyn Smyth - Ulster University
2. Mr. Adrian Pugsley - Ulster University
3. Mr. George Hanna - Ulster University
4. Dr. Aggelos Zacharopoulos - Ulster University
5. Dr. Jayanta Mondol - Ulster University
6. Dr. Ahmad Besheer - Ulster University

Numerical study of PCM integration impact on overall performances of a highly building integrated solar collector (Paper 04)
1. Dr. Fabrice Motte - University of Corsica
2. Dr. Gilles Notton - University of Corsica
3. Dr. Chrysovalantou Lamnatou - University of Lleida

4. Prof. Christian Cristofari - University of Corsica
5. Prof. Daniel Chemisana – University of Catalonia

Wednesday 8th March Paper Session 8: St. Laurence's

Chairs: Prof. Adolfo Palombo and Dr. Jasna Radulovic

The Potential of Concrete Solar Thermal Collectors for Energy Savings (Paper 55)
1. Mr. Richard O'Hegarty - Trinity College Dublin
2. Dr. Oliver Kinnane - University College Dublin
3. Dr. Sarah McCormack - Trinity College Dublin

Optimization assessment of the energy performance of a BIPV/T-PCM system using Genetic Algorithms (Paper 54)
1. Mr. Ricardo Pereira - LNEG
2. Dr. Laura Aelenei - LNEG

Investigating the potential for flexible demand in an office building with a BIPV façade and a PV roof system (Paper 53)
1. Prof. Daniel Aelenei - Nova University of Lisbon-Faculty of Cience and Technology
2. Mr. Miguel Santos - Nova University of Lisbon-Faculty of Cience and Technology
3. Dr. Laura Aelenei - LNEG

Building Integrated Photovoltaics in the overall building energy balance: Lithuanian Case (Paper 49)
1. Mr. Rokas Tamasauskas - Institute of Architecture and Construction of Kaunas University of Technology, Lithuania
2. Dr. Rosita Norvaisiene - Kaunas University of Applied Engineering Sciences, Tvirtoves al., Kaunas, Lithuania
3. Dr. Vytautas Sucila - Faculty of Electrical and Electronics Engineering of Kaunas, Lithuania

Modular Building Intergraded Solar-Thermal Flat Plate Hot Air Collectors (Paper 43)
1. Prof. Soteris Kalogirou - Faculty of Engineering and Technology, Cyprus University of Technology
2. Dr. Georgios Florides - Faculty of Engineering and Technology, Cyprus University

POSTER SESSION & ART EXHIBITION (Prof. Yiannis Tripanagnostopoulos)

Thursday 9th March: Paper: Session 9. St. Laurence's

Chairs: Prof. Aleksandra Krstic Furundzic and Dr. Chrysovalanto Lamnatou

Modular Building Intergraded Solar-Thermal Flat Plate Hot Water Collectors (Paper 42)
1. Prof. Soteris Kalogirou - Faculty of Engineering and Technology, Cyprus University of Technology
2. Dr. Georgios Florides - Faculty of Engineering and Technology, Cyprus University

Passive Solar Floor Heating in Buildings utilizing the Heat from an Integrated Solar Flat Plate Collector (Paper 41)
1. Dr. Georgios Florides - Faculty of Engineering and Technology, Cyprus University of Technology
2. Prof. Paul Christodoulides - Faculty of Engineering and Technology, Cyprus University of Technology
3. Prof. Soteris Kalogirou - Faculty of Engineering and Technology, Cyprus University

Adaptive solar building envelope with thermal energy storage (Paper 39)
1. Ms. Shauli Chakraborti - Ulster University
2. Dr. Jayanta Mondol - Ulster University

3. Dr. Mervyn Smyth - Ulster University
4. Dr. Aggelos Zacharopoulos - Ulster University
5. Mr. Adrian Pugsley - Ulster University

Geometrical Optimization of the Urban Fabric in order to ensure the Viability of Building Integration of Active Solar Systems (Paper 31)
1. Dr. Andreas Savvides - University of Cyprus
2. Mr. Constantinos Vassiliades - University of Cyprus
3. Dr. Aimilios Michael - University of Cyprus

A Review of Possible Pathways for Avoiding Snow and Ice Formation on Building Integrated Photovoltaics (Paper 29)
1. Mr. Per-Olof Andersson - Norwegian University of Science and Technology (NTNU)
2. Prof. Bjørn Petter Jelle - Norwegian University of Science and Technology (NTNU) and SINTEF Building and Infrastructure
3. Dr. Tao Gao - Norwegian University of Science and Technology (NTNU)
4. Dr. Serina Ng - SINTEF Building and Infrastructure
5. Dr. Josefine Selj - Institute for Energy Technology (IFE)
6. Dr. Sean Erik Foss - Institute for Energy Technology (IFE)
7. Prof. Erik Stensrud Marstein - Institute for Energy Technology (IFE) and University of Oslo (UiO)
8. Dr. Tore Kolås - SINTEF Materials and Chemistry

Economics of building-integrated solar thermal systems (Paper 26)
1. Dr. Christoph Maurer - Fraunhofer Institute of Solar Energy Systems ISE
2. Dr. Mervyn Smyth - Ulster University

Design of an inverted absorber compound parabolic concentrator for solar air heating (Paper 58)
1. Mr. Fernando Guerreiro - Dublin Institute of Technology
2. Prof. David Kennedy - Dublin Institute of Technology
3. Prof. Michael Mc Keever - Dublin Institute of Technology
4. Prof. Brian Norton - Dublin Institute of Technology

Thursday 9th March: Paper: Session 10. St. Laurence's

Chairs: Prof. Yiannis Tripanagnostopoulos and Prof. Ion Visa

A Review of Materials Science Research Pathways for Building Integrated Photovoltaics (Paper 21)
1. Prof. Bjørn Petter Jelle - Norwegian University of Science and Technology (NTNU) and SINTEF Building and Infrastructure
2. Mr. Per-Olof Andersson - Norwegian University of Science and Technology (NTNU)
3. Ms. Anna Fedorova - Norwegian University of Science and Technology (NTNU)
4. Dr. Tao Gao - Norwegian University of Science and Technology (NTNU)
5. Dr. Serina Ng - SINTEF Building and Infrastructure
6. Dr. Josefine Selj - Institute for Energy Technology (IFE)
7. Dr. Sean Erik Foss - Institute for Energy Technology (IFE)
8. Prof. Erik Stensrud Marstein - Institute for Energy Technology (IFE), and, University of Oslo (UiO)
9. Dr. Tore Kolås - SINTEF Materials and Chemistry (NTNU)

Building Integration of Solar Thermal Systems - Exemple of a Refubirshment of a Church Rectory (Paper 19)
1. Prof. Christian Cristofari - University of Corsica
2. Dr. Mihail-Bogdan Carutasiu - University Politehnica of Bucharest
3. Dr. Jean-louis Canaletti - University of Corsica -IUT
4. Dr. Rosita Norvaisiene - Kaunas University of Applied Engineering Sciences
5. Dr. Fabrice Motte - University of Corsica
6. Dr. Gilles Notton - University of Corsica

The Pilot Photovoltaic/Thermal Plant at the University of Catania: description and preliminary characterization (Paper 17)
1. Prof. Giuseppe Tina - University of Catania
2. Prof. Antonio Gagliano - University of Catania
3. Prof. Francesco Nocera - University of Catania
4. Prof. Alfio Dario Grasso - University of Catania

Thermal mass performance of concrete panels incorporated with phase change materials (Paper 16)
1. Ms. Dervilla Niall - Dublin Institute of Technology
2. Dr. Oliver Kinnane - University College Dublin
3. Dr. Roger West - Trinity College Dublin
4. Dr. Sarah McCormack - Trinity College Dublin

Multicriterial Optimization of Procedures for the Selection the Best Measures for Energy Performances Improvement of the Multifamily Housing in Belgrade (Paper 14)
1. Prof. Aleksandra Krstic-Furundzic - University of Belgrade, Faculty of Architecture
2. Dr. Tatjana Kosic - University of Belgrade, Faculty of Architecture

Large-Scale Laboratory Investigation of Building Integrated Photovoltaics –A Review of Methods and Opportunities (Paper 30)
1. Ms. Anna Fedorova - Norwegian University of Science and Technology (NTNU)
2. Prof. Bjørn Petter Jelle - Norwegian University of Science and Technology (NTNU), and, SINTEF Building and Infrastructure
3. Mr. Erlend Andenæs - Norwegian University of Science and Technology (NTNU)
4. Dr. Anne Gerd Imenes - Teknova, and, University of Agder (UiA)
5. Mr. Ole Aunrønning - Norwegian University of Science and Technology (NTNU)
6. Dr. Christian Schlemminger - SINTEF Building and Infrastructure
7. Prof. Stig Geving - Norwegian University of Science and Technology (NTNU)

Thursday 9th March: Paper: 2pm to 3.30pm H2020 MEETING. St. Laurence's

Presented by Philip Cheasty, Irish National Contact Point, H2020 (Energy), Enterprise Ireland and Mrs. Katherine Eve., Renewable Energy Journal.

Thursday 9th March: 3.30pm. Close of Conference: Prof. Brian Norton & Prof. Soteris Kalogirou

POSTER PAPERS

Solar Photovoltaic System Inverter Configuration Performance Analysis for a Building Integrated System Experiencing Shade (Paper 97)
Ms. Lynette O'Callaghan – DIT, Dr. Michael Mckeever - Dublin Institute of Technology,
Prof. Brian Norton - Dublin Institute of Technology

Building Integrated Compound Parabolic Photovoltaic Concentrator: A review (Paper 94)
Dr. Sarah McCormack - Trinity College Dublin, Ms. Anita Ortega - Department of Civil, Structural and Environment Engineering, Trinity College Dublin, College Green, Dublin 2, Ireland, Ms. Hoda Akbari - Department of Civil, Structural and Environment Engineering

Modelling of Synthetic Natural Gas Production via Biomass Gasification for Renewable Gas Grid Injection (Paper 93)
Dr. Wayne Doherty - Mechanical Engineering Dublin Institute of Technology

Integration and replication of the Bfirst BIPV products, from the perspective of a Global General Contractor Company (Paper 98)
Jose C. Esteban, Acciona.

Solar Air Shutter with Split-System (Paper 99)
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Smart Façade Air Solar Collector System – SFA SCSys (Paper 100)
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COST Action TU1205:
Building Integration of Solar Thermal Systems (BISTS)

Overview of the Action:

Energy use in buildings represents 40% of the total primary energy used in the EU and therefore developing effective energy alternatives is imperative. Solar thermal systems (STS) will have a main role to play as they contribute directly to the heating and cooling of buildings and the provision of domestic hot water. STS are typically mounted on building roofs with no attempt to incorporate them into the building envelope, creating aesthetic challenges and space availability problems. The Action will foster and accelerate long-term development in STS through critical review, experimentation, simulation and demonstration of viable systems for full incorporation and integration into the traditional building envelope. Viable solutions will also consider economic constraints, resulting in cost effective Building Integrated STS. Additionally, factors like structural integrity, weather impact protection, fire and noise protection will be considered. The most important benefit of this Action is the increased adoption of RES in buildings. Three generic European regions are considered; Southern Mediterranean, Central Continental and Northern Maritime Europe, to fully explore the Pan-European nature of STS integration. The Action consortium presents a critical mass of European knowledge, expertise, resources, skills and R&D in the area of STS, supporting innovation and conceptual thinking.

Action web page: http://www.tu1205-bists.eu/

Domain: Transport and Urban Development (TUD).

http://www.cost.eu/COST_Actions/tud/Actions/TU1205

Countries participating: Austria, Belgium, Bulgaria, Cyprus, Denmark, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Lithuania, Malta, Netherlands, Poland, Portugal, Romania, Serbia, Spain, Turkey, United Kingdom.

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The importance of the solar systems to achieve the nZEB level in the energy renovation of southern Europe's buildings

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Abstract: Nowadays, in the European Union the construction rate of new buildings is very low and therefore achieving the EU targets at the energy consumption level of the building sector is only possible through nearly zero energy renovation of the existing building stock. Reducing energy consumption through passive measures is a priority but this is not enough to achieve the nearly Zero Energy Building (nZEB) level. Therefore, the active systems, namely those that allow harvesting the solar energy to partially replace the use of non-renewable energy, are one of the best solutions to consider. At this level, solar thermal and photovoltaic panels play an important role, mainly in countries with high levels of solar radiation, as in the Southern European countries. Nevertheless, there are still some barriers to overcome for the broader dissemination of the implementation of these systems. One of the most important is that building owners are not fully aware of the life-cycle benefits that systems have at the economic level. As in every new different design approach, the best way to arise awareness is through the analysis of case studies, highlighting the reduced life-cycle costs and potential environmental impacts and other long-term benefits resulting from the integration of these active solutions. Thus, this paper is aimed at assessing the contribution of the solar systems to achieve three levels of energy performance (Basic Renovation, nearly Zero Energy Buildings - nZEB and Zero Energy Buildings - ZEB) in the energy renovation of a multifamily building located in Portugal. From the results, it is possible to conclude that, on an annual basis, and for the Portuguese climate, it is possible to overcome, a large amount of the energy needs for acclimatization and domestic hot water preparation with the integration of these systems. The study also shows attractive cost and carbon payback times resulting from their use.

1. Introduction

Improving the buildings' energy performance is an important part of the EU 2020 and 2030 energy targets as well as of the roadmap for moving towards a competitive low carbon economy in 2050 (EPBD recast 2010; EC 2014a; EC 2014b). The targets defined for 2020 are 20% reduction in energy consumption, 20% reduction in carbon emissions and 20% increase in renewable energy use (EPBD recast 2010). The EU framework on climate and energy for 2030 is committed to reducing, until 2030, EU domestic carbon emissions by 40% when compared with the 1990 level and 25% reduction in energy consumption (EC 2014b). This target will ensure that EU is on the cost-effective track towards meeting its objective of cutting emissions by at least 80% by 2050 (EC 2014a). The Commission also proposes an objective of increasing the share of renewable energy to at least 27% of the EU's energy consumption by 2030 (EC 2014b). Based on these new targets, renovation towards nZEB is now a goal of the European countries.

The nZEB performance is achieved by: reducing the buildings' energy needs, through passive approaches (e.g. improving insulation levels, optimizing solar gains and using external shading systems and night cooling); selecting efficient appliances and systems (e.g. lighting, heating, cooling and ventilation systems); and on-site production of renewable energy to reduce the remaining non-renewable energy use. Solar thermal and photovoltaic systems together with biomass and geothermal energy sources are the most common energy sources used in buildings. In buildings, especially in building renovation, solar thermal and photovoltaic systems can be easily added or integrated into facades and/or roofs and therefore show a greater potential to be used as renewable energy systems than other systems (Gorgolis & Karamanis 2016).

To achieve the defined targets, it is necessary to improve the performance of the existing building stock due to its representativeness in the overall building stock and poor energy performance. Additionally, the small rate of new building construction in Europe (1–2% per year) makes energy savings insignificant if the focus is only on new building construction (EC 2011). The renovation of existing buildings is an opportunity to improve their energy performance that is many times missed. The two main barriers for the dissemination of energy renovation of buildings are the high initial costs and the lack of know-how and awareness regarding the cost-effectiveness of the energy retrofit measures (Bartiaux et al. 2014), especially if a life cycle cost approach is not considered and ancillary benefits of energy retrofit measures are ignored. Ancillary benefits of retrofit measures beyond energy savings include lower noise levels and improved comfort from insulation and glazing, better indoor air quality and temperature control from new HVAC systems, less operational maintenance or increased energy security against energy price fluctuations by the deployment of renewable energy resources (Boermans et al. 2011). After reducing the energy losses and controlling the unwanted heat gains it is necessary to use renewable energy systems to supply the remaining energy needs of the building.

Buildings require energy both in the form of heat (e.g. for the domestic hot water preparation, space heating and space cooling) and electricity (e.g. for lighting, electric appliances, heating and cooling). This energy can be supplied using solar thermal (STC), photovoltaic (PV) and hybrid photovoltaic-thermal (PVT) systems.

Supported by the conclusions of other studies (e.g. Lamnatou et al., 2015a), solar systems show to be effective in reducing the whole buildings life-cycle impacts and therefore this is an aspect that should be taken into account in the feasibility studies regarding the benefits of using solar systems. Therefore it is necessary to implement cost-effective strategies for increased efficiency and deployment of renewable energy to achieve the best building performance (e.g. less energy use, fewer carbon emissions and higher co-benefits related with indoor environmental quality) at the lowest possible effort (e.g. initial costs, life cycle costs and occupant's disturbance in the case of building renovation). Based on this context, this paper is aimed at assessing the contribution of the solar systems to achieve three levels of energy performance (Basic Renovation, nZEB and Zero Energy Buildings - ZEB) in the energy renovation of a multifamily building located in Portugal.

2. Case study and Methodology

In this study a typical Portuguese multifamily building is analysed. Its main facades are oriented to the northeast and southwest and this building represents the Portuguese multifamily housing stock built between 1990 and 2000. This case study is equivalent to 41% of the total Portuguese multifamily housing stock (LNEC 2013). It has three floors, a half buried basement used as a garage, 18 apartments (nine two-bedroom dwelling and nine three-bedroom dwellings). The building implantation area is 600 m^2 and has 1279 m^2 of net area.

The building has a reinforced concrete structure and beam and pot slabs. There is no insulation in the building envelope, as it was the common practice at the time. The exterior walls are cavity wall construction (two masonry panes with an air gap, without thermal insulation) with render on the inside and outside surface; the windows are double glazed with aluminium frames; the floors are lightweight slabs; and the roof is pitched with ceramic roof tiles. The roof has 2 cm of mineral wool placed over the last slab and there is a 2 cm thick expanded polystyrene (EPS) insulation in the slab between the common garage (non-heated area) and the first floor. Each apartment has a gas heater for domestic hot water (DHW) production (efficiency of 0.87) and there are no central heating or cooling systems, just portable electric heaters and fan coils, which is the common situation in this type of dwelling (LNEC 2013).

The properties of the building before and after each one of the studied renovation scenarios are shown in Table 1. Portuguese regulations define that the nZEB solution corresponds to the cost-optimal renovation solution of the envelope.

Table 1. Properties of the building before and after each of the renovation scenarios

Properties of building	Before renovation (only maintenance)	Basic renovation (fulfils minimum legal requirements)	nZEB renovation	ZEB renovation
Thermal transmittance, W/(m²·K)				
U_{wall}	0.96	0.54	0.47	0.47
U_{roof}	1.01	0.45	0.31	0.31
U_{floor}	0.86	0.60	0.29	0.29
$U_{window\ (glass/\ frame)}$	3.10	2.70	2.40	2.40
U_{door}	3.10	3.10	2.40	2.40
Linear thermal transmittance, W/(m·K)				
$\Psi_{wall/wall}$	0.55	0.50	0.50	0.50
$\Psi_{roof/wall}$	1.00	1.00	1.00	1.00
$\Psi_{floor/wall}$	0.75	0.50	0.50	0.50
$\Psi_{window/wall}$	0.25	0.25	0.25	0.25
$\Psi_{window/shutter\ box}$	0.30	0.30	0.30	0.30
$\Psi_{door/wall}$	0.25	0.25	0.25	0.25
$\Psi_{balcony/wall}$	-	-	-	-
Internal heat gains (heat from inhabitants, appliances, equipment and lighting)	4.0 W/m²			
Ventilation (air change rate)	0.94 ach	0.79 ach	Winter: 0.55 ach Summer: 0.6 ach	Winter: 0.55 ach Summer: 0.6 ach
Heating system type and efficiency Cooling system type and efficiency	Radiator (1.0) HVAC system (3.5)	Radiator (1.0) HVAC system (3.5)	HVAC (4.1) HVAC system (3.5)	HVAC (4.1) HVAC system (3.5)
DHW preparation system type and efficiency	Natural gas heater (0.75)	Solar thermal collectors and natural gas heater (0.75)	Solar thermal collectors and new natural gas heater (0.87)	Solar thermal collectors and new natural gas heater (0.87)
Renewable energy sources		-		
Solar collectors for DHW, m²	-	40	80	80
Solar panels for electricity production, m²	-	-	0	135

This analysis is aimed at presenting, at the building scale, together with the cost and energy analysis, the potential environment life-cycle impacts resulting from different renovation scenarios. To archive this goal, the methodology is based on the analysis of the: i) life-cycle impacts resulting from each scenario, using a standardized LCA method (EN 15978 (CEN 2012)); ii) economic payback time (EPBT); and carbon emissions payback time (GPBT). For the calculation of the energy needs the methodology of the Portuguese regulation for the thermal performance of residential buildings was followed (Portugal 2013), which is based on the quasi-steady state method presented in ISO 13790 (ISO 2008).

The costs of the renovation scenarios and the related maintenance costs were estimated based on market surveys. The energy costs are based on Portuguese energy prices and the estimation of the evolution of the energy prices for the calculation period follows the scenario given by EC (EC 2012/C 115/01 2012). The average prices of energy (VAT included) considered were 0.22 €/kWh for the electricity and 0.08 €/kWh for natural gas. The global costs of each of the retrofit scenarios defined earlier refer to the net present value (NPV) of the capital costs for the initial retrofit works and replacements during the considered period of 30 years, the maintenance costs and the energy costs, with a discount rate of 3%.In all the renovation scenarios, materials, workmanship and maintenance costs were considered. The life span and the annual preventive maintenance including operation, repair and servicing costs in % of the initial investment of the systems defined in the EN 15459 standard were considered. The radiators, fan coils, gas heater, HVAC systems and solar thermal systems were replaced after 20 years and the PV system after 25 years (in accordance with manufacturers' warranties).

The costs considered in the maintenance scenario are the reparation of cracks and the cleaning and painting of the facade and the replacement of the roof tiles (removal of the tiles and transport to landfill and installation of the new roof tiles). Additionally, the radiators and fan coils and the gas heater were also replaced for equivalent ones. In the basic renovation, the costs considered are the cost of the materials and workmanship of the renovation works (repair of cracks, cleaning the facade, application of the ETICS on the façade, application of the insulation on the roof and garage's ceiling, replacement of the roof tiles and of the windows) and the systems and fittings (radiators, cooling system, gas heater, storage tank and solar thermal collectors). In the nZEB and ZEB renovation, the costs considered are the cost of the materials and workmanship of the renovation works (repair of cracks, cleaning the facade, application of the ETICS on the façade, application the insulation on the roof and garage's ceiling, replacement of the windows and roof tiles) and the systems and fittings (gas heater, HVAC systems for heating and for cooling, storage tank and solar thermal collectors). Additionally, the ZEB scenario includes the costs of the PV system.

3. Presentation and Analysis of Results

3.1. Energy performance

The results of the energy simulations carried out for the four different scenarios are presented in Table 2. From the analysis of Table 2 it is possible to verify that compared to existing building the reduction in the primary energy consumption is around 32%, 74% and 100% respectively for the basic, nZEB and ZEB renovation. The reduction in the primary energy consumption of the nZEB renovation compared to the basic renovation scenario is around 61%. In the ZEB scenario the building has a positive balance of 0.4 kWh/(m^2·year) in the delivered energy.

3.2. Life-cycle costs

The investment costs of the renovation (envelope and systems) and of the replacement of the systems at the end of their lifetime (20 for all the systems but the PV system that is 25 years) are high. Therefore, it is important to analyse, for each renovation scenario, the evolution of the lifetime cumulative costs of each renovation scenario (Figure 1). As Figure 1 shows, the Basic renovation has the shorter payback time, about 13.5 years. nZEB and ZEB renovation scenarios payback time is around 14 years, approximately half of the lifetime of the systems installed. Analysing Figure 1 it is also possible to understand that the contribution of renovation works and systems acquisition (year 0) in the overall lifetime impacts is considerable, as well as the replacement of the systems (years 20 and 25), especially in nZEB and ZEB renovation scenarios. It is also possible to see the reduced effect of the PV system cost in the ZEB renovation scenario when compared with the nZEB scenario.

Table 2. Results of energy simulations for the different scenarios

Properties of building	Before renovation (only maintenance)	Basic renovation (fulfils minimum legal requirements)	nZEB renovation	ZEB renovation
Building's energy needs (net energy, without system losses), kWh/(m^2·year)				
Space heating	57.3	37.1	27.2	27.2
Space cooling	2.2	2.8	3.7	3.7
Domestic hot water	29.3	29.3	29.3	29.3
Delivered energy (energy use of technical systems with systems losses) net energy, kWh/(m^2·year)				
Space heating	57.3	37.1	6.6	6.6
Space cooling	0.6	0.8	1.1	1.1
Domestic hot water	39.1	33.7	33.7	33.7
Produced energy on site, kWh/(m^2·year)				
Solar collectors (heat)	0	19.4	27.5	27.5
PV panels (electricity)	0	0	0	14.3
Primary energy use, kWh$_{PE}$/(m^2·year)				
Energy performance value, kWh$_{PE}$/(m^2·year)	184.0	125.4	48.4	0.0

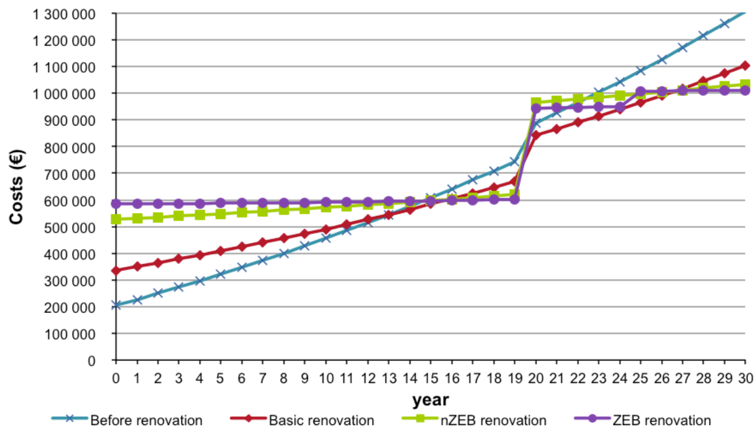

Fig. 1. Lifetime cumulative energy costs of each renovation scenario

These results show that considering the lifetime costs, the nZEB and ZEB renovations are cost effective and that the acquisition and the replacement of the HVAC systems, STC and PV systems and gas heater are both amortized before the end of the renovation lifetime (30 years).

3.3. Environmental performance

Table 3 presents, for each renovation scenario, the building products inputs related with the construction works of each renovation scenario.

Table 4 presents, for each renovation scenario, the annual equivalent lifecycle impacts and the potential improvements compared to the performance of the existing building. In the assessment of the performance of the existing building only the maintenance related impacts are considered. As recommend by the EN 15978 (CEN 2011), for the ZEB scenario, Table 9 presents separately the benefits resulting from the electricity produced in the PV panels as "benefits outside the system boundary". Reasoning for this is that PV panels are connected with the public electricity network and 100% of the produced renewable electricity is exported to this network. Nevertheless, these benefits are deducted from the lifetime inside boundary's impacts in order to allow comparisons with the other scenarios.

Table 3. Inventory of used building products

Inventory item	Before renovation (only maintenance)	Basic renovation (fulfils minimum legal requirements)	nZEB renovation	ZEB renovation
Lifetime material input (kg)				
Water-based paint	1278.20	1278.20	1278.20	1278.20
Synthetic mortar		7101.10	7101.10	7101.10
Expanded polystyrene (EPS)		757.80	1486.34	1486.34
Mineral wool (MW)		852.00	1533.60	1533.60
Aluminium window sills		260.70	287.70	287.70
Lifetime windows renovation (m^2)				
Aluminium windows with double glazed glass		96.03		
PVC windows with double glazed glass			96.03	96.03

Table 4. Annual equivalent life-cycle impacts per net floor area and potential improvements resulting from each renovation scenario

Environmental indicator	Before renovation (only maintenance)	Basic renovation (fulfils minimum legal requirements)		nZEB renovation		ZEB renovation			
	Impacts ($/m^2$.year)	Impacts ($/m^2$.year)	Improvement (%)	Impacts ($/m^2$.year)	Improvement (%)	Impacts of the physical boundaries ($/m^2$.year)	Benefits outside the system boundary	Overall impacts ($/m^2$.year)	Improvement (%)
ADP_elements	4,75E-05	6,20E-05	-30%	1,05E-04	-121%	2,13E-04	1,08E-05	2,02E-04	-326%
ADP_FF	5,80E+02	3,70E+02	36%	1,01E+02	83%	1,32E+02	1,11E+02	2,05E+01	96%
GWP100a	4,25E+01	2,80E+01	34%	7,38E+00	83%	9,88E+00	8,49E+00	1,86E+00	96%
ODP	2,95E-06	2,01E-06	32%	6,07E-07	79%	1,14E-06	6,10E-07	5,25E-07	82%
POCP	1,29E-02	9,23E-03	28%	2,71E-03	79%	3,71E-03	2,72E-03	9,82E-04	92%
AP	3,01E-01	2,13E-01	29%	5,93E-02	80%	7,92E-02	6,72E-02	1,20E-02	96%
EP	7,11E-02	5,35E-02	25%	1,88E-02	74%	2,90E-02	1,69E-02	1,20E-02	83%
CED_NRE	6,18E+02	3,98E+02	36%	1,11E+02	82%	1,46E+02	1,20E+02	2,55E+01	96%
CED_TOT	7,19E+02	4,67E+02	35%	1,27E+02	82%	1,69E+02	1,45E+02	3,22E+01	96%

From the analysis of Tables 2 and 4 it is possible to conclude that the lower the energy consumption of a renovation scenario is the better is the environmental performance. Since the goal of the nZEB scenario was to reduce in 80% the primary energy needs of the existing building (before renovation), results show good correlation between the reduction of energy needs and the reduction of the overall potential environmental impacts. These results also highlight that he contribution of the energy related impacts in the overall potential environmental life-cycle impacts is much higher when compared with the contribution of the building integrated energy systems and embodied impacts of building products. This means that the thermal retrofitting of building envelopes together with the integration of solar systems (STC and PV) is a good principle to significantly reduce the life-cycle impacts of a building.

According to several authors (e.g (Mateus & Bragança 2011; Mateus et al. 2013; EPA Science Advisory Board 2000) the environmental impact category that most influences the overall environmental performance is the Global Warming Potential (GWP). Therefore, it is relevant to analyse, for each renovation scenario, the evolution of this impact category along the considered lifetime (Figure 2). From the analysis of Figure 2 it is possible to understand that the contribution of renovation works (Year 0) in the overall lifecycle impacts is very low. It is also possible to see the reduced effect of replacing the STC systems in the three renovation scenarios (year 20) and the effect of replacing the PV system in the ZEB scenario (year 25). Due to the avoided CO_2 emissions related to the production of renewable electricity in the PV panels integrated in the ZEB scenario, it is possible to see the slightly decrease of the accumulated GWP along the considered lifetime. Compared with the before renovation scenario, the emissions saved in the lifetime are 549 ton.CO_2eq., 1340 ton.CO_2eq. and 1560 ton.CO_2eq. for the Basic, nZEB and ZEB scenario, respectively. Additionally, it is possible to conclude that the Greenhouse Emissions Payback Time (GPBT) of each scenario is around 5 years, 1.5 years and 2 years for the Basic, nZEB and ZEB scenario, respectively.

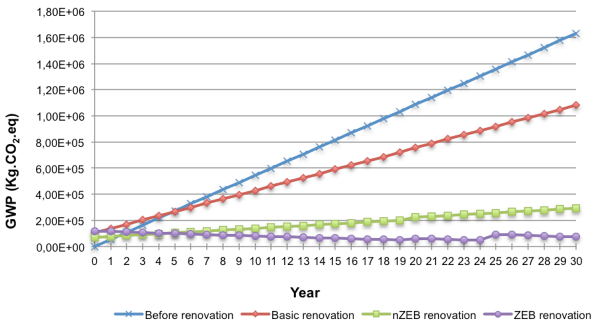

Fig. 2. Lifetime Cumulative Global Warming Potential (GWP) of each renovation scenario

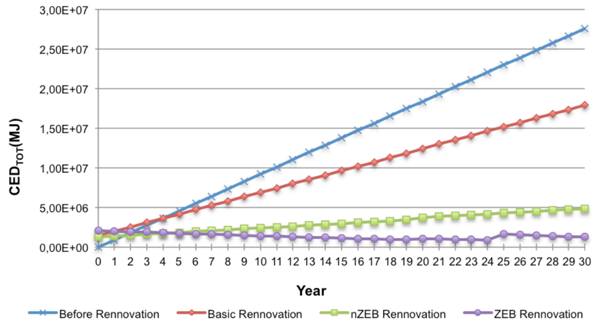

Fig. 3. Lifetime Cumulative Energy Demand (CED_{TOT}) of each renovation scenario

Figure 3 shows the lifetime Cumulative Energy Demand (total) – CED_{TOT} - of the four renovation scenarios. The CED_{TOT} considers both the renewable and non-renewable embodied energy in the building products and energy systems used and the delivered energy consumed during the building operation phase and in the operation. It also includes maintenance and replacement of the building energy systems. Comparing Figure 2 with Figure 3, the results show good correlation with the CO_2 cumulative emissions, showing the importance of the energy consumption in the potential environmental impacts. Compared with the before renovation scenario, the lifetime saved CED_{TOT} is 9 670 GJ (2 686 111 kWh), 22 700 GJ (6 305 556 kWh) and 26 300 GJ (7 305 556 kWh), for the Basic, nZEB and ZEB scenarios respectively. Additionally, it is possible to conclude that the energy payback time (EPBT) of each renovation scenario is around 4 years, 1.5 years and 2 years for the Basic, nZEB and ZEB scenario, respectively.

4. Conclusions

This paper studied four renovation scenarios (maintenance, basic, nZEB and ZEB) for a multifamily building located in the suburbs of Porto, Portugal. The building is representative of 41% of the Portuguese residential building stock and represents the buildings built between 1990 and 2000. For each renovation scenario the economic payback time and greenhouse emissions payback time for the materials and systems used were assessed. To study the efficiency of each renovation scenario this paper calculated the lifetime costs and energy consumption using the Portuguese thermal regulation methodology. Additionally, the payback time of the renewable energy systems was also estimated. In conclusion, this study shows that the considered scenarios for the implementation of the nZEB and ZEB energy levels in Portuguese multifamily buildings are cost effective while providing important potential environmental benefits during the lifetime of a renovation scenario (30 years). The energy prices variation and the discount rate might change the results of the analysis and in some situations the use of solar thermal and PV systems might not be adequate due to the shading of the surrounding buildings or an insufficient area to install the solar thermal and PV panels. In this situation an alternative renewable energy source should be considered, depending on the location of the building.

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References

Bartiaux, F. et al., 2014. A practice–theory approach to homeowners' energy retrofits in four European areas. *Building Research & Information*, 42(4), pp.525–538.

Boermans, T. et al., 2011. *Principles for Nearly Zero-Energy Buildings - Paving the way to effective implementation of policy requirements*.

CEN, 2012. *EN 15804:2012. Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products*,

CEN, 2011. *EN 15978:2011. Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method*,

EC, 2014a. 2030 climate and energy goals for a competitive, secure and low-carbon EU economy.

EC, 2014b. A policy framework for climate and energy in the period from 2020 to 2030 - Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

EC, 2011. COM(2011) 112 final. A Roadmap for moving to a competitive low carbon economy in 2050 - Communication From the Commission to the European Parliament, the Council, the European Economic and Social Committee and the committee of the regions.

EC 2012/C 115/01, 2012. Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology f. *Official Journal of the European Union*, p.28.

EPA Science Advisory Board, 2000. *Towards an Integrated Environmental Decision-Making*, Washigton, DC.

EPBD recast, 2010. *EU-Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings*,

Gorgolis, G. & Karamanis, D., 2016. Solar energy materials for glazing technologies. *Solar Energy Materials and Solar Cells*, 144, pp.559–578.

ISO, 2008. *ISO 13790:2008 - Energy performance of buildings -- Calculation of energy use for space heating and cooling*, Geneva.

LNEC, I.&, 2013. Parque Habitacional e a sua Reabilitação - Análise e Evolução.

Mateus, R. et al., 2013. Sustainability assessment of an innovative lightweight building technology for partition walls – Comparison with conventional technologies. *Building and Environment*, 67, pp.147–159.

Mateus, R. & Bragança, L., 2011. Sustainability assessment and rating of buildings: Developing the methodology SBToolPT–H. *Building and Environment*, 46(10), pp.1962–1971.

Portugal, 2013. *Regulamento de Desempenho Energético dos Edifícios de Habitação [Portuguese Thermal Regulation]. Decreto-Lei no 118/2013 de 20 de Agosto, Portugal, 2013.*