

GIS-Based Energy Consumption Model at the Urban Scale for the Building Stock

*Original*

GIS-Based Energy Consumption Model at the Urban Scale for the Building Stock / TORABI MOGHADAM, Sara; Mutani, Guglielmina; Lombardi, Patrizia (EUR). - In: JRC Conference and Workshop Reports / Paolo Bertoldi. - ELETTRONICO. - [s.l.] : European Union, 2016. - ISBN 978-92-79-59779-4. - pp. 56-63 [10.2790/290244]

*Availability:*

This version is available at: 11583/2646750 since: 2020-02-25T15:29:54Z

*Publisher:*

European Union

*Published*

DOI:10.2790/290244

*Terms of use:*

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

*Publisher copyright*

(Article begins on next page)



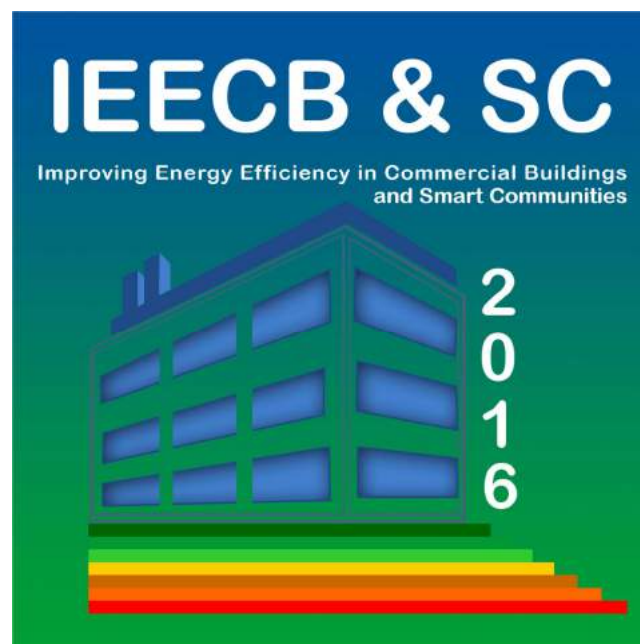
JRC CONFERENCE AND WORKSHOP REPORTS

# 9th International Conference Improving Energy Efficiency in Commercial Buildings and Smart Communities

*IEECB&SC'16*

Paolo Bertoldi

2016



Joint  
Research  
Centre

EUR 27993 EN

# 9th International Conference Improving Energy Efficiency in Commercial Buildings and Smart Communities

This publication is a Conference and Workshop report by the Joint Research Centre, the European Commission's in-house science service. It aims to provide evidence-based scientific support to the European policy-making process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

**Contact information**

Name: Paolo Bertoldi

Address: TP.450, Via Enrico Fermi, 2749, 21027 Ispra VA, Italia

E-mail: [paolo.bertoldi@ec.europa.eu](mailto:paolo.bertoldi@ec.europa.eu)

Tel.: +39 0332 78 9299

**JRC Science Hub**

<https://ec.europa.eu/jrc>

JRC102161

EUR 27993 EN

ISBN 978-92-79-59779-4 (PDF)

ISSN 1831-9424 (online)

doi:10.2790/290244 (online)

© European Union, 2016

Reproduction is authorised provided the source is acknowledged.

All images © European Union 2016

How to cite: Paolo Bertoldi; 9th International Conference Improving Energy Efficiency in

Commercial Buildings and Smart Communities; EUR 27993 EN; doi:10.2790/290244

# Table of Content

## Session Cities I

Integrated and sustainable energy concepts for urban neighbourhoods – A generic approach based on Austrian experiences (31) <i>Gerhard Hofer, Christof Amann and Daniela Bachner</i> <i>e7 Energie Markt Analyse GmbH (Austria)</i> .....	1
The Covenant of Mayors: In-depth Analysis of Sustainable energy Action Plans (5) <i>Silvia Rivas, Giulia Melica, Albana Kona, et al.</i> <i>Joint Research Centre of the European Commission (EU)</i> .....	14
Investigating the Impacts of Community Energy Projects on Local Stakeholders (53) <i>Ayi Iboh and Ibrahim Motawa</i> <i>Heriot Watt University (UK)</i> .....	29
Integrated process of Ecosystem Services evaluation and urban planning. The experience of LIFE SAM4CP project towards sustainable and smart communities (49) <i>Carolina Giaimo, Dafne Regis and Stefano Salata</i> <i>DIST - Politecnico di Torino (Italy)</i> .....	43

## Session Cities II

GIS-Based Energy Consumption Model at the Urban Scale for the Building Stock (3) <i>Sara Torabi Moghadam, Patrizia Lombardi and Guglielmina Mutani</i> <i>Politecnico di Torino (Italy)</i> .....	56
New 3D simulation methods for Urban Energy Planning (76) <i>Ursula Eicker, Jürgen Schumacher and Volker Coors</i> <i>Hochschule für Technik (Germany)</i> .....	64
GIS based bottom-up approach to evaluate the energy demand for the SINFONIA district Innsbruck (AT) (20) <i>Dominik Pfeifer, Daniel Fischer, Petra Mautner and Wolfgang Streicher</i> <i>University of Innsbruck (Austria)</i> .....	74

## Session Cities III

Building Stock Modelling - A novel instrument for urban energy planning in the context of climate change (62) <i>Claudio Nägeli, Martin Jakob and Benjamin Sunarjo</i> <i>TEP Energy GmbH (Switzerland)</i> .....	87
Public-Private Partnerships in Microgrid Development (42) <i>Sebastian Dern</i> <i>LEVEL Agency for Infrastructure (USA)</i> .....	95
Lessons Learnt from an Urban Community: the "Concerto AL Piano" experience (95) <i>Roberto Pagani, Corrado Carbonaro and Lorenzo Savio</i> <i>Politecnico Torino (Italy)</i> .....	113

## Session Cities IV

Campus and Community Energy Master Planning in North America based on European Best Practice (78) <i>Oliver Baumann, Annie Marston and Gerd Fleischhammer</i> <i>Baumann Consulting (USA)</i> .....	125
---	-----

Achieving Greater Energy Efficiency through the Transition from Net Zero Energy Buildings to Net Zero Energy Settlements (86) <i>Afroditi Synnefa, Konstantina Vasilakopoulou and Matthaios Santamouris</i> <i>National and Kapodistrian University of Athens (Greece)</i> .....	139
--	-----

Operational Efficiency of the UK Community Energy Ownership Models (54) <i>Ayi Iboh and Ibrahim Motawa</i> <i>Heriot Watt University (UK)</i> .....	146
---	-----

Crowdfunding in the energy sector: a smart financing and empowering tool for citizens and communities? (111) <i>Chiara Candelise</i> <i>Bocconi University (Italy)</i> .....	158
--	-----

## Session Lighting

A lighting retrofit intervention for energy savings and comfort optimization in an industrial building (14) <i>Laura Bellia, Giuseppe Boccia, Giorgia Di Serafino, et al.</i> <i>DII - Università di Napoli Federico II (Italy)</i> .....	182
---	-----

Sustainable outdoor lighting for reducing energy and light waste (69) <i>Andreas Hänel, Lambros Doulos, Sibylle Schroer, Cătălin D. Gălățanu, Frangiskos Topalis</i> <i>Fachgruppe Dark Sky, Museum am Schölerberg (Germany)</i> .....	202
--	-----

When should LED technology be used in an energy efficiency upgrade? (19) <i>Cynthia Jolley-Rogers and Paul Bannister</i> <i>Projects and Advisory Division (incorporating Exergy Australia) Energy Action (Australia)</i> ...	213
---	-----

Flicker, buzz, instability, and poor low-end performance: understanding an overcoming LED lighting dimming challenges (75) <i>Sam Woodward</i> <i>Lutron EA Ltd. (UK)</i> .....	225
---	-----

## Session Building Example

Best practice commercial buildings from Upper Austria (41) <i>Christiane Egger and Christine Öhlinger</i> <i>OÖ Energiesparverband (Austria)</i> .....	231
--	-----

Lessons from the Leading Edge: What Drives Australia's Most Efficient Buildings? (17) <i>Paul Bannister</i> <i>Energy Action (Australia)</i> .....	237
--	-----

How the renovation of government - owned listed buildings can contribute to achieve both cultural and energy efficiency goals (61) <i>Pablo Villarejo and José Ramón Gámez</i> <i>Polytechnic University of Madrid (Spain)</i> .....	252
--	-----

## Session Building Automation I

European certification method for assessing the building automation impact on energy efficiency in buildings (10) <i>Bonnie Brook and Andrei Litiu</i> <i>European Building Automation and Controls Association (Belgium)</i> .....	263
---	-----

How can EU policy frameworks best capture the potential for energy savings in the EU through the use of building automation technology? (33) <i>Paul Waide, Diederik Debusscher and Hans De Keulenaer</i> <i>Waide Strategic Efficiency Ltd (UK)</i> .....	275
--	-----

Energy performance contracting, the royal road to increasing the competitive advantage of businesses by improving energy efficiency (9) <i>Volker Dragon and Andrei Litiu</i> <i>eu.esco (Belgium)</i> .....	291
--	-----

## Session Building Automation II

Synthesis and Refinement of Artificial HVAC Sensor Data Intended for Supervised Learning in Data-Driven AFDD Techniques (34) <i>David McCabe, Daniel Coakley, Catherine Conaghan and Ruth Kerrigan</i> <i>Integrated Environmental Solutions Ltd. (UK)</i> .....	300
Cloud Enabled Smart Controller for Non-Domestic Building (44) <i>Abbas Javed, Hadi Larijani, Ali Ahmadinia, Rohinton Emmanuel and Des Gibson</i> <i>Glasgow Caledonian University (UK)</i> .....	307
Can Energy Efficiency Services in buildings be seen as a Cleantechnology? (11) <i>Dirk Franco</i> <i>UHasselt/PXL (Belgium)</i> .....	322
Who's in Control: A Look at Control Systems Characteristics, Energy and Roles in Net Zero Buildings (55) <i>Cathy Higgins, Alexi Miller and Mark Lyles</i> <i>New Buildings Institute (USA)</i> .....	331

## Session Policies & Programmes I

Design for Performance: the ingredients needed to implement an energy performance guarantee - proven in Australia, can they work elsewhere? (73) <i>Robert Cohen, Bill Bordass and Paul Bannister</i> <i>Verco (UK)</i> .....	348
Investing in Building Energy Efficiency to preserve Natural Capital and Human Capital (98) <i>Rohini Srivastava and Vivian Loftness</i> <i>Carnegie Mellon University (USA)</i> .....	361
The CEN and ISO Standards on Energy Performance of Buildings assessment procedures, allowing maximal flexibility and transparency (72) <i>Jaap Hogeling</i> <i>ISSO (The Netherlands)</i> .....	373

## Session Policies & Programmes II

Lessons learned from NABERS and Energy Star - relevance to next iteration of EPBD? (97) <i>Adam Hinge, Paul Bannister and Lane Burt</i> <i>Sustainable Energy Partnerships (USA)</i> .....	383
Energy efficiency in public buildings under the EU Cohesion Policy in the 2007- 2013 programming period – insights from the ex post evaluation (109) <i>Martin Nesbit, Kamila Paquel, Andrea Illes, Xavier Le Den, et al.</i> <i>Institute for European Environmental Policy (UK)</i> .....	398
Who does what with data? A WICKED approach to energy strategies (101) <i>Kathryn Janda, Russell Layberry</i> <i>University of Oxford (UK)</i> .....	419

## Session Policies & Programmes III

Energy Saving Cost Curves as a tool for policy development - case study of the German building stock (108) <i>Lukas Kranzl, Filippos Anagnostopoulos, Dan Staniaszek, et al.</i> <i>Technische Universität Wien (Austria)</i> .....	434
Efficiency potentials of building technologies and their contribution to the energy and climate change mitigation goals (60) <i>Martin Jakob, Marc Melliger, Giacomo Catenazzi and Remo Forster</i> <i>TEP Energy GmbH (Switzerland)</i> .....	453
A business-oriented roadmap towards the implementation of circular integrated facades (45) <i>Juan Francisco Azcárate-Aguerre, Tillmann Klein and Alexandra C. den Heijer</i> <i>TU Delft (The Netherlands)</i> .....	463

## Session Retail Buildings & Health Care I

Interactions of retrofitted shopping centres with local energy grids (37) <i>Matthias Haase, Javier Antolin, Annamaria Belleri</i> <i>SINTEF Building and Infrastructure (Norway)</i> .....	475
Smart shopping centres, controlled emission: roof top PV power generation for a clean metropolitan city Dhaka, Bangladesh (43) <i>Majbaul Alam, Mezanur Rahaman and Subhes Bhattacharyya</i> <i>De Montfort University (UK)</i> .....	487
Improving Energy Efficiency in Existing Health Care Facilities (24) <i>James Carson, Christos Vidalakis and Joseph Tah</i> <i>Oxford Brookes University (UK)</i> .....	497
Reducing hospital electricity use: an end-use perspective (80) <i>Paula Morgenstern</i> <i>UCL (UK)</i> .....	509

## Session Retail Buildings & Health Care II

How Does Energy Efficiency Work? Shopping Malls in Istanbul (84) <i>Ebru Acuner, Seher Ates, Mustafa Berker Yurtseven and Sermin Onaygil</i> <i>Istanbul Technical University Energy Institute (Turkey)</i> .....	524
CommONEnergy – Transforming shopping malls into lighthouses of energy efficient architectures (89) <i>Maarten De Groot, Raphael Bointner, Agne Toleikyte, Matthias Haase and Ruth Woods</i> <i>BPIE (Belgium)</i> .....	531
Ecoshopping: Energy Efficient Retrofitting Solutions for Retail Buildings – A Review of the Best Practice (7) <i>Andy Lewry and Ed Suttie</i> <i>Building Research Establishment (UK)</i> .....	547

## Session Data Centres

Tapping design and optimization potentials of ICT equipment and data centres (65) <i>Thomas Egli, Martin Jakob, Remo Forster, Claudio Nägeli and Adrian Altenburger</i> TEP Energy GmbH (Switzerland) .....	570
Energy Efficiency in Data Centres: Best Practices and Results (103) <i>Paolo Bertoldi</i> Joint Research Centre of the European Commission (EU) .....	582
Marketing Data Centre Power Flexibility (105) <i>Sonja Klingert and Maria Perez Ortega</i> University of Mannheim (Germany) .....	592

## Session ESCO

Progress Report about European project EnPC INTRANS: Capacity Building on Energy Performance Contracting in European Markets in Transition (3/2015-2/2017) (1) <i>Konstanze Stein</i> KEA Climate Protection and Energy Agency Baden-Württemberg GmbH (Germany) .....	606
Energy Performance Contracting Plus: SME Partnerships for Innovative Energy Services through standardisation (6) <i>Aristotelis Botzios-Valaskakis, Stefan Amann and Erik van Agtmaal</i> Centre for Renewable Energy Sources and Energy Saving (Greece) .....	616
Business and Technical Models for Deep Energy Retrofit - Findings from IEA Annex 61 (30) <i>Ruediger Lohse and Alexander Zhivov</i> KEA (Germany) .....	634
Review of Business Models for Energy Services Companies for Commercial Buildings (104) <i>Paolo Bertoldi</i> Joint Research Centre of the European Commission (EU) .....	656

## Session HVAC

Aspects of Energy use by UK Air Conditioning (74) <i>Roger Hitchin, Christine Pout, Andy Lewry, Alan Abela and Lorna Hamilton</i> Building Research Establishment (UK) .....	669
About actual management of large HVAC systems and about most attractive retrofit opportunities (70) <i>Cleide Aparecida Silva, Jules Hannay and Jean Lebrun,</i> Université de Liège (Belgium) .....	684
Efficiency and intelligence in new and existing offices (110) <i>Consiglia Mocerino</i> (Italy) .....	697
Experimental validation of different air flow correlations for natural ventilation (79) <i>Daniel Gürlich, Tobias Erhart, Maximilian Haag, Ursula Eicker and Maren Schulz</i> University of Applied Sciences Stuttgart (Germany) .....	715

## Session Monitoring I

Implementation of building occupancy monitoring in office building: the BOCS project (12) <i>Olivia Guerra-Santin, Tomasz Jaskiewicz, Jantien Doolgaard, et al.</i> Delft University of Technology (The Netherlands) .....	723
--	-----

Supporting Building Portfolio Investment and Policy Decision Making through an Integrated Building Utility Data Platform (40) <i>Azizan Aziz, Bertrand Lasternas, Vivian Loftness, et al.</i> Carnegie Mellon University (USA) .....	733
Study on Database for Energy Consumption of Commercial Buildings (DECC) Part 3 Secular Change of Energy Consumption after the Great East Japan Earthquake in Commercial buildings (48) <i>Hiroto Takaguchi, Takehito Imanari, Shigeki Kametani, Koichi Osawa and Shuzo Murakami</i> Waseda University (Japan) .....	741
SWIVT as a case-study on energy management platforms supporting design, planning and operation of smart districts (47) <i>Mira Conci and Jens Schneider</i> TU Darmstadt (Germany) .....	754
<b>Session Monitoring II</b>	
Supporting Energy efficiency Decisions with Energy Consumption Data Analyses (90) <i>Erica Cochran, Flore Marion and Hetal Parekh</i> Carnegie Mellon University (USA) .....	771
Energy profile of Energy Assessments for Buildings Associated with Small Businesses (82) <i>Monick Kumar Mahareddy, Bhaskaran Gopalakrishnan, Amir Abolhassani and Ashish Nimbarte</i> West Virginia University (USA) .....	783
Study on hypermarket energy consumption with a Key Performance Indicator evaluation system (83) <i>He Cai and Wei Qingpeng</i> Tsinghua University (China) .....	796
<b>Session Monitoring III</b>	
Analysis of detailed building energy consumption Using Database and Simulation tool (52) <i>Hiroki Tsunekawa, Shigeki Kametani, Eiji Hara, et al.</i> Tokyo University of Marine Science and Technology (Japan) .....	814
Advances in Data Science for Building Energy Management (59) <i>Juan Gomez Romero, Carlos Fernandez Basso, M. Dolores Ruiz, et al.</i> Universidad de Granada (Spain) .....	828
Data gathering and architecture aspects of a major EU wide energy efficiency project for SMEs (23) <i>Neil Brown, Paul Fleming, Nicoletta Favaretto and Niall Sandford</i> DeMontfort University (UK) .....	835
Reaching energy-efficiency through customer segmentation – addressing customers according to their goal-orientation (88) <i>Goelz Sebastian and Kristin Goldbach</i> Fraunhofer Institute for Solar Energy Systems ISE (Germany) .....	844

## Session Polygeneration

- Assessing Capital Investment on Energy Efficiency Projects from a Global Energy Management Perspective. A Tri-generation Case Study (81)  
**Ronan Coffey, Raymond Sterling, Noel Finnerty, Daniel Coakley and Marcus Keane**  
*National University of Ireland (Ireland)* .....857
- Development of Performance Evaluation Method for Cogeneration Systems - Measurement Data Analysis and Development of Simulation Program (18)  
**Takahiro Ueno, Yuichi Takahiro Ueno, Daisuke Sumiyoshi and Masato Miyata**  
*Kyushu University (Japan)* .....866
- Biomass Trigenation System for Retail Stores (29)  
**Llorente Javier, Diaz De Garayo Sergio and Zambrano Daniel**  
*CENER (Spain)* .....874
- Optimal cooling load sharing in trigeneration plants for a District Heating and Cooling network (21)  
**Benedetto Conte, Joan Carles Bruno and Alberto Coronas**  
*Universitat Rovira i Virgili (Spain)* .....886

## Session NZEBs I

- Balancing Energy Efficiency and Renewables (13)  
**Jessica Grove-Smith, Wolfgang Feist and Benjamin Krick**  
*Passive House Institute (Germany)* .....894
- Demonstrating Nearly Zero Energy Hotels in Europe.Examples and experiences from the European initiative neZEH (57)  
**Theocharis Tsoutsos, Stavroula Tournaki, Maria Frangou, et al.**  
*Technical University of Crete (Greece)* .....903
- Economic strategies for Low-Energy Industrial Buildings (25)  
**Pascal Brinks**  
*Astron Buildings (Luxembourg)* .....912

## Session NZEBs II

- Towards sustainable and smart communities: integrating energy efficient technologies into buildings through a holistic approach (85)  
**Theoni Karlessi, Nikos Kampelis, Denia Kolokotsa and Mat Santamouris**  
*University of Athens (Greece)* .....920
- Evaluating the Benefits of Exposing the Thermal Mass in Future Climate Scenarios to Reduce Overheating (51)  
**Carlos Jimenez-Bescos**  
*Anglia Ruskin University (UK)* .....928
- Energy consumption – A comparison between prediction and measured performance (28)  
**Oliver Ottinger, Soeren Peper and Wolfgang Feist**  
*Passive House Institute (Germany)* .....935
- Implementation of nearly zero energy buildings (NZEBs) retrofit in Europe: a focus on the non-residential building sector (71)  
**Delia D'Agostino, Daniele Paci, Paolo Zangheri, and Barbara Cuniberti**  
*Joint Research Centre of the European Commission (EU)* .....949

**Poster Session**

Innovative approaches for retail planning. The Trentino experience (Italy) (35)  
*Ombretta Caldarice and Grazia Brunetta* .....962

Integration of user perspective when selecting sustainability measures (36)  
*Thomas Baeumer, Patrick Mueller, Tobias Popovic, Daniel Worm and Stefan Zimmermann* .....973

HumbleBee is not a bug, but an innovative lighting system (112)  
*A. Pasqua, L. Blaso, S. Fumagalli, G. Leonardi, A. Antonelli, P. Pistochini* .....985

Case study of deep retrofitting of a residential building towards plus energy level (63)  
*Matthias Haase* .....994

# Session Cities II

# GIS-Based Energy Consumption Model at the Urban Scale for the Building Stock

Sara Torabi Moghadam<sup>1</sup>, Guglielmina Mutani<sup>2</sup>, Patrizia Lombardi<sup>1</sup>

<sup>1</sup> *Interuniversity Department of Regional and Urban Studies and Planning, Politecnico di Torino,*

<sup>2</sup> *Department of Energy, Politecnico di Torino*

## Abstract

Energy efficient buildings' issue integrated into the district and CO<sub>2</sub> emission reduction strategies and policies is one of the main concerns in the European Union (EU). In order to achieve an effective impact, instead of just concentrating on the improvement in terms of energy efficiency to one particular building, this approach requires challenges to be solved in an entire municipality or an entire district. Accordingly, it is significant understanding the comprehensive residential building stock models in the urban environment able to promote a sustainable energy planning. In this paper we describe a new methodology based on two different modelling approaches top-down and bottom-up with the aim to evaluate the buildings energy consumption model of a municipality. This methodology is mainly based on information that is already available on building stock from the literature and data collection (i.e., technical department of municipality, web, energy auditors and others) which is later transferred into the Geographic information system (GIS). Into this in future studies GIS platform provides the information on energy performance in the whole city as well as creating the urban energy maps for assessing retrofitting scenarios and support decision making for policy implementation to achieve sustainable urban planning. This study is part of an ongoing Smart City research study, national cluster project named Zero Energy Buildings in Smart Urban Districts (EEB) and is tested in a medium sized town in the Piedmont region (Italy), and the results are discussed.

Keyword: Geographic Information System (GIS), Thermal Energy Consumption Model, Building Stock, Urban Scale

## Introduction

Nowadays, there is an immense impact on energy demand and consequently GHG emissions due to the way that cities are acting and growing [1]. In Italy, the energy balance in 2013 has demonstrated a further reduction of the energy demand for about -1.9% compared to 2012 level. This trend is happening not just due to the economic crisis, but also to the result of the successful implementation of energy efficiency policies. Indeed, the end users of energy accounted for about 126.6 (Mtoe) with a reduction of 1% compared to 2012. It is noteworthy that only sector where the energy consumption has increased is the construction one (+ 5.6%) [2].

Particularly in the building sector, energy consumption is influenced by the spatial organization. Therefore, where the purpose is the assessment of globally achievable energy savings and the greenhouse gases reduced emissions, it is crucial to broaden the focus on the building stock at urban scale [3]. Accordingly, many different approaches and tools are developed for the spatial representation of energy demand, production and CO<sub>2</sub> emissions such as a Geographical Information Systems (GIS). The implementation of spatial analysis through GIS tools can be important to manage, archive, analysis, and geo-referenced visualization of the energy data and to optimize the energy sources available on the territory [4].

It is required to understand the building energy performance in an entire district or municipality to achieve a sustainable energy planning strategies that speed up the energy renovation and energy efficiency procedure in needed existing buildings [6]. In fact, the Sustainable Energy Action Plan (SEAP) promoted by the European Commission brings up the strategies for realizing the greenhouse gas reductions required by 2020 for municipalities that have joined the Covenant of Mayors [5]. There are numerous approaches that have been conducted to evaluate the energy consumption model for a

large building stock (i.e. Real monitored data [7] considering a cadastre found out from a big number of individual certifications [8] or Census data [9]). Accordingly, with the aim of the energy consumption reduction, many building energy regulations are approved (e.g. codes, standards, etc.) in most of the developed countries [10]. Several types of research have been carried out primarily in order to investigate the methodologies for single building's energy performance [11], [12] or for building stock [13]. In this study, the attention is focused on the residential building stock at urban scale.

There are two general methodologies to modelling energy use that are used for building sector: 'top-down' and 'bottom-up' methods. The top-down approach uses historic aggregate energy values reported by energy suppliers and estimates the energy consumption of housing stock as a function of top-level variables. These variables comprise macroeconomic indicators (e.g. unemployment, inflation and gross domestic product), energy price, and general climate. As this model is based on historical information, therefore, it is not adequate for the evaluating the impact of new technologies on energy consumption. The residential energy demand system for Spain [14] is an example of this kind of model. The bottom-up method accounts for the estimated or simulated energy consumption for a specific individual or group of houses. This approach involves two categories: the statistical method and the engineering method. The adaptive neural network technique that [15] applied to a building in Montreal and the conditional demand analysis model used by [16] for San Diego are two examples of statistical bottom-up models.

This work is focusing on a method for evaluating the thermal energy consumption of residential building stock in one of the municipality in Piedmont (Italy) "Settimo Torinese" which is, representing approximately 46875 inhabitants [21] based on GIS for mapping energy consumption profile. The main goal of this work is to show that the energy-efficient strategy for a Smart City of the future should start on its existing building stock.

## Methodology

The methodology used in this study is based on the literature that is partly mentioned in the previous section where the models used for the energy assessment of existing residential buildings can be divided into two categories [17]:

- Top-Down models: energy-use data at urban scale are compared with climate variables, census results, and statistical surveys to determine average energy consumption for existing buildings. These models can compare different variables, but cannot distinguish spatial variations in energy consumption of a Municipality or a territory.
- Bottom-Up models: these models, at building scale, are used to evaluate the energy balance of a single building with high detail; together, a set of energy consumption models, can be combined to evaluate the energy consumption of blocks of buildings, districts or cities; to achieve a valid and high quality results at urban scale a large number of data which is explained in the next section related to the buildings is required. These models can be also used to evaluate energy savings model after building retrofits.

In this case, it has been implemented a hybrid approach where the single building models, derived by the bottom-up approach, were used to represent the energy consumption of residential buildings in a district or a city through a detailed spatial representation considering the heated volume, the period of construction, and the compactness of residential buildings. While the statistical models at urban scale, derived by the top-down approach, were used to validate the above energy buildings' models taking into account the spatial variability of the urban context, the socio-economic level, the type of users, the buildings' retrofit level and other important factors influencing the energy-use of buildings.

In the following paragraph the description of the data used for the bottom-up and top-down approaches is described. Particularly, the calibration of the two models has been made, introducing correction coefficients in the bottom-up approach at buildings scale to get the overall consumptions at Municipal scale as reported in the SEAP. These correction coefficients take into account the characteristics of the built heritage and the typical users influencing the energy consumptions (e.g. the buildings' retrofit level and the users' behavior).

## Evaluation of thermal energy of residential buildings in large urban context

For the evaluation of Space heating energy consumption of residential buildings, it can be considered some advantageous indicators as a period of construction, compactness and density of the buildings [3], [18]. In this work has been considered the climate with the Heating Degree Days (HDD), the compactness of buildings with the surface to volume ratio (S/V) and the period of construction with different levels of the envelopes' thermal insulation and systems' efficiencies to calculate the energy consumption on existing buildings [19]. The sources of data needed are essential:

i) Energy-use data: Sustainable Energy Action Plan (SEAP), considering 2009 as a reference year for the case study [5]; ii) Buildings use, Heating Volume, Building Geometry: The Database Spatial Reference Entities (BDTRE) Piedmont, other information as the height of the buildings and the type of roof obtained from Lidar datasets, Digital Terrain Model of Piedmont Region (DTM) [20]; iii) Demographic data: The 2011 ISTAT at census section scale [21]; iv) Climate data: outdoor air temperature and the Heating Degree Days (HDD) by climatic ARPA database [22]. As the energy consumption considered in the "Action Plan for sustainable energy" referred to the year 2009, the model was taken into account the HDD for that year. It was considered the climatic data recorded at the Brandizzo Malone weather station, as the closest station in terms of geographical coordinates (45°10'37" N, 7°50'08" E, 192 (m s.l.m.) to Settimo Torinese (45°08'26" N, 7°45'49" E, 212 m s.l.m.).

For this research, the ArcGIS 10.2 is used to analysis energy consumption [25]. Considering the spatial distribution of the heated volumes, for residential buildings with different characteristics, the energy-use of the single buildings' models was applied on an urban scale. The 2011 ISTAT census data were also used to improve the models considering the average percentage of the heated volume, the type of buildings' envelope, systems' efficiency, the period of construction, and the number of inhabitants on census section scale. The proposed methodology can be divided into following steps:

1. The residential building stock has extracted from the Database Spatial Reference Entities (BDTRE) Piedmont [20];
2. The surface to volume ratio  $S/V_{real}$  has calculated (Figure 1(a)). This ratio is classified as Detached House  $S/V \geq 0,72$ ; Terrace house  $0,57 \leq S/V \leq 0,71$ ; Row house  $0,46 \leq S/V \leq 0,56$ ; Tower  $S/V \leq 0,45$  [23], [24];
3. The construction period has attributed for every residential building (Figure 1(b)), where is classified as <1919; 1919-1945; 1946-1960; 1961-1970; 1971-1980; 1981-1990; 1991-2000; 2001-2005; >2005 [21];



Figure 1, (a) surface to volume ratio  $S/V$  calculated for residential buildings and (b) the building construction period attributed for case study (elaborated by authors)

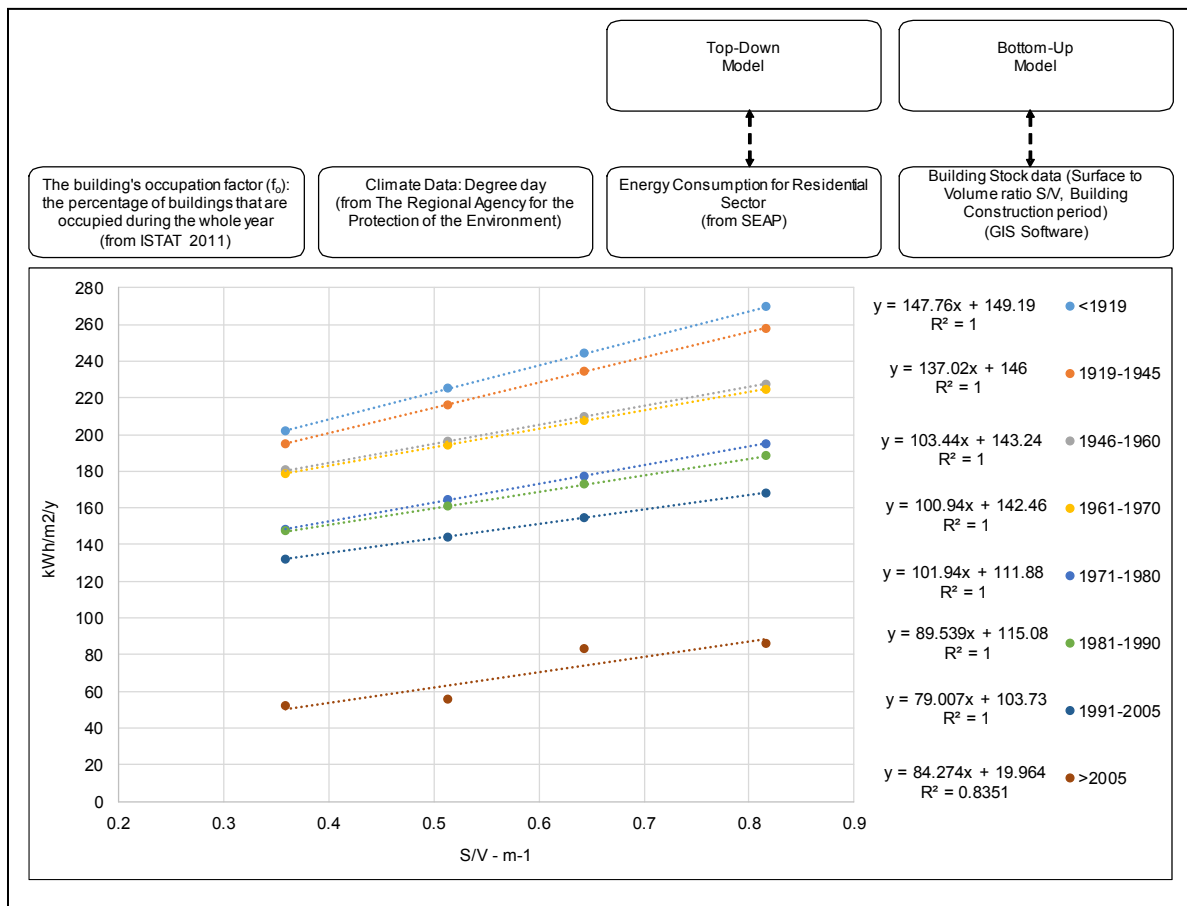
4. The energy demand has calculated using the model started from the model of Torino [24].

Comparing the bottom-up and top-down results, correction factors can be determined to calibrate the bottom up results to achieve good results at Municipal scale. The simplified models of space heating energy-use developed in the bottom-up approach do not take into account significant factors such as solar gains, indoor/outdoor air temperatures and, specially, the refurbishment of buildings. To consider these variables and to adapt the model to real energy consumption data, the model of the specific energy-use of buildings was multiplied by a correction factor and the demographic aspect [23].

For the city of Settimo Torinese, the energy consumption correlations have been defined starting from the model of Torino [24] corrected by the HDD (normalized on the average value of the Heating Degree Days of the last 10 years). These linear correlations used to simulate the energy-use EPgl (for space heating and domestic hot water production) as a function of the surface e to volume ratio S/V for Settimo Torinese are shown in Figure 2, where;

$$EPgl \text{ (kWh/m}^2\text{/y)} = \text{Slope (kWh/m/y)} \cdot S/V \text{ (m}^{-1}\text{)} + \text{Constant (kWh/m}^2\text{/y)}$$

The models consider the statistical percentage of the real heated volumes, the existence of uninhabited dwellings (the average value for Settimo Torinese is 0.83; from the census) and the correction factor = 1.19 depending on the different use and type of buildings while these values for Torino are respectively 0.94 and 1.04. The correction factors are average values for each city depending by the different territory, residential users, and buildings characteristics.



**Figure 2. The specific energy-use for space heating and hot water production as function of the building construction period and the surface to volume ratio S/V for residential buildings for Settimo Torinese.**

The specific energy-use EPgl for space heating and hot water production's model have a coefficient of determination  $R^2 = 1$  except in the case of construction period after 2005 ( $R^2 = 0.8351$ ), showing that the variation of energy-use can be explained as a function of the surface to volume ratio S/V for each period of construction.  $R^2$  indicates how well the statistical model fits the data and, since the Torino model has been used [19], the coefficient of correlation for Settimo Torinese is equal to 1 by meaning

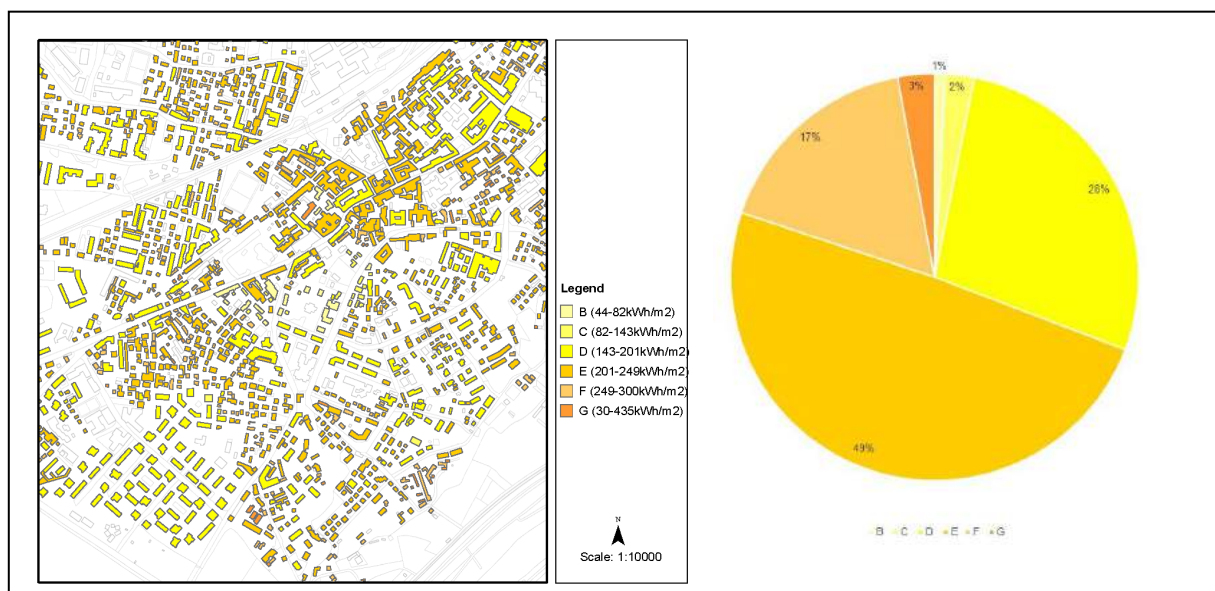
that the regression line perfectly fits the data. The simplified linear equation models used to simulate the energy-use for the cities of Torino and Settimo torinese are defined in Table 1.

**Table 1, Linear model of specific energy-use (kWh/m<sup>2</sup>/y) for space heating and hot water production as function of surface to volume ratio S/V and period of construction for residential buildings in Torino and Settimo Torinese.**

Buildings' construction period	Torino (2462 HDD)		Settimo Torinese (2926 HDD)	
	Slope kWh/m/y	Constant kWh/m <sup>2</sup> /y	Slope kWh/m/y	Constant kWh/m <sup>2</sup> /y
<1919	130.82	140.75	147.76	149.19
1919-1945	121.31	137.93	137.02	146
1946-1960	91.58	135.49	103.44	143.24
1961-1970	89.37	134.80	100.94	142.46
1971-1980	90.26	107.72	101.94	111.88
1981-1990	79.27	110.56	89.539	115.08
1991-2005	69.95	97.61	79.007	103.73
>2005	100.84	22.02	84.274	19.964

## Results

Integrating the Top-down and Bottom-up models, it is obtained the average annual energy-use for space heating and hot water production equal to 218 kWh/m<sup>2</sup>/y. In Figure 3 is shown the energy classes of the Piedmont Region [26] and the number of buildings belonging to those classes. The building more energy efficient is located in class B ( $EP_{gl, average} = 68.25 \text{ kWh/m}^2/\text{y}$ ) with the construction period after year 2006 and the surface to volume ratio  $S/V_{average} = 0.57 \text{ m}^{-1}$ . While the building with less efficient class G ( $EP_{gl, average} = 324.04 \text{ kWh/m}^2/\text{y}$ ) are mostly belong to the construction period year <1919 and  $S/V_{average} = 1.33 \text{ m}^{-1}$  with 1 floor.



**Figure 3, Energy efficiency classes kWh/m<sup>2</sup>/y and the percentage number of buildings belonging to those classes.**

As shown in Table 2, the number of buildings for different periods of construction and for energy certification classes (space heating and domestic hot water production), the more recent buildings

belong to the better energy classes rather than older. It is happening due to the effective implementation of the energy efficiency policies and laws.

**Table 2, Number of buildings for different periods of construction and for energy classes.**

Energy efficiency classes kWh/m <sup>2</sup> /y	Construction period									Tot.
	< 1919	1919 - 1945	1946 - 1960	1961 - 1970	1971 - 1980	1981 - 1990	1991 - 2000	2001 - 2005	> 2006	
A+ < 27	-	-	-	-	-	-	-	-	-	-
A 27-43	-	-	-	-	-	-	-	-	-	-
B 44-81	-	-	-	-	-	-	-	-	25	25
C 82-142	-	-	-	-	-	-	20	8	38	66
D 143-200	1	2	68	240	181	149	103	59	1	804
E 201-248	36	66	332	816	125	51	2	5	-	1433
F 249-299	65	99	115	208	5	-	-	-	-	492
G 300-435	31	38	11	5	-	-	-	-	-	85
N.C. > 435	-	-	-	-	-	-	-	-	-	-
Tot.	133	205	526	1269	311	200	125	72	64	2905

## Conclusion and future study

The European Directives, including the Energy Efficiency Directive 2012/27/EU [28], emphasize that big effort must be made by a Member States to optimize the use of energy sources. This can be achieved through an energy efficiency plan, setting several policy targets as reduction in EU greenhouse gas emissions, raising the share of EU energy consumption produced from renewable resources and energy efficiency improvement. Despite the great energy efficiency improvements in buildings, recent energy consumption data analyses show that these targets will unlikely is reached [27].

Therefore, the assessment of the residential building energy consumption at city/municipal scale is significant to achieve the energy efficiency goals in EU. The importance of the period of construction and shape factor of buildings is discussed, where more recent buildings belong to the greater energy classes due to the current effective implementation of the energy efficiency regulations. On the other hand, it can be obtained the same conclusion for the surface to volume ratio S/V: the single-family houses belong to the low energy classes, rather than the compact buildings, as towers.

Therefore, it is crucial to define a comprehensive profile model to understand the current state of the energy consumption for building stock. This paper began by calculating the energy consumption profile at the City Scale with the use of geographic information systems (GIS) that can significantly help in the planning of actions. The estimation of energy-use for each residential building of the case study was calculated through the methodology described. For the future study, it will compare the bottom-up measured energy consumption and the calculate one. Afterward, it will calculate the renovation rate for residential building stock, taking into account the social variables. Particularly, a multi-criteria decision-making will be applied to achieve a sustainable and smart energy planning as a method, which has fascinated the decision makers' attention for a long time [29].

## Acknowledgment

The work included in this paper has been supported by the Research Project "Zero Energy Buildings in Smart Urban Districts".

## References

[1] IPCC 2014, *Climate Change 2014: Mitigation of Climate Change Intergovernmental Panel on Climate Change*. New York, NY: Cambridge University Press. <http://www.ipcc.ch/>

- [2] ENEA. (2015). *Annual Report Energy Efficiency*. Rome: Technical Unit for Energy Efficiency. <http://www.enea.it/it/pubblicazioni/pdf-volumi/raee-2015.pdf>.
- [3] Fracastoro G. V. and Serraino, M. *A methodology for assessing the energy performance of large scale building*. Energy and Buildings. 2011, pp. 844-852.
- [4] Ascione F., Francesca De Masi R., De Rossi F., Fistola R. and Sasso, M. *Analysis and diagnosis of the energy performance of buildings and districts: Methodology, validation and development of Urban Energy Maps*. Cities. 2013, pp. 270-283.
- [5] SEAP 2012, *Sustainable Energy Action Plan, Sustainable Energy Action Plan of the Union of Municipalities "Unione NET"* (In Italian). [http://www.pattodeisindaci.eu/actions/sustainable-energy-action-plans\\_it.html](http://www.pattodeisindaci.eu/actions/sustainable-energy-action-plans_it.html)
- [6] Dall'O' G., Galante A. and Torri, M. *A methodology for the energy performance classification of residential building stock on an urban scale*. Energy and Buildings. 2013, pp. 211-219.
- [7] Balaras C. A., Droutsas K., Dascalaki E. and Kontoyiannidis S. *Heating energy consumption and resulting environmental impact of European apartment buildings*. Energy and Building. 2005, pp. 429-442.
- [8] CENED. (2015). CENED, *Certificazione energetica degli edifici*. Retrieved 09 02, 2015, from <http://www.cened.it>
- [9] Balaras C. A., Gagliola A. G., Georgopoulou E., Mirasgedis S., Sarafidis Y. and Lalas D. P. *European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings*. Building and Environment. 2005, pp. 1298-1314.
- [10] Iwaro, J. and Mwashia A. *A review of building energy regulation and policy for energy conservation in developing countries*. Energy Policy. 2010, pp. 7744-7755.
- [11] Malmqvist T. and Glaumann M. *Environmental efficiency in residential buildings – A simplified communication approach*. Building and Environment. 2009, pp. 937-947.
- [12] Kalz D. E., Pfafferoth J. and Herkel S. *Building signatures: A holistic approach to the evaluation of heating and cooling concepts*. Building and Environment. 2010, pp. 632-646.
- [13] Ballarini I. and Corrado V. *Application of energy rating methods to the existing building stock: Analysis of some residential buildings in Turin*. Energy and Buildings. 2009, pp. 790-800.
- [14] Labandiera X. and Labeaga J. M. *A Residential Energy Demand*. The Energy Journal, 2006, pp. 87-111.
- [15] Yang J., Rivard H and Zmeureanu R. *Building energy prediction with adaptive artificial neural networks*. Proc. Ninth International IBPSA Conference (Montréal, Canada, 15-18 Aug., 2005, pp. 1401-8.)
- [16] Parti M. and Parti C. *The total and appliance-specific conditional demand for electricity in the household sector*. The Bell J of Economics. 1980, pp. 309-21.
- [17] Kavgić M., Mavrogiann, A., Mumović D., Summerfield, A., Stevanović, Z. and Djurović-Petrović, M. *A review of bottom-up building stock models for energy consumption in the residential sector*. Building and Environment. 2010, pp. 1683-1697.
- [18] Magrini A., Pernetti R. and Magnani L. *Energy consumption of existing buildings, some considerations* (In Italian). La Termotecnica. May. 2001, pp. 54-56.
- [19] Mutani G. and Pairona, M. *A model to evaluate the heating energy consumption for residential buildings in Turin* (In Italian). L'UFFICIO TECNICO. 2011, pp. 21-36.
- [20] <http://www.geoportale.piemonte.it/geocatalogorp/?sezione=catalogo>

[21] <http://www.istat.it/it/archivio/104317>

[22] <https://www.arpa.piemonte.gov.it/rischinaturali/accesso-ai-dati/selezione-gradi-giorno/selezione-gradi-giorno.html>

[23] Mutani G. and Vicentini, G. *Buildings' Energy Consumption, Energy Savings Potential and the Availability of Renewable Energy Sources in Urban Spaces*. Journal of Civil Engineering and Architecture Research. 2015, PP. 1102-1115.

[24] Mutani G. and Vicentini, G.). *Analysis of the thermal energy demand in buildings with geographic software free. The case study of Turin* (In Italian). LA TERMOTECNICA. Jul.-Aug. 2013, PP. 63-67.

[25] <http://www.esri.com/software/arcgis/arcgis-for-desktop>

[26] D.G.R. n. 43-11965 del 4 August 2009. It can be downloaded at : <http://www.regione.piemonte.it/energia/>

[27] Lombardi P. and Trossero E. *Beyond energy efficiency in evaluating sustainable development in planning and the built environment*, International Journal of Sustainable Building Technology and Urban Development. 2014, pp. 274-282.

[28] The European Parliament and the Council of the European Union,. Directive 2012/27/EU of the European parliament and of the council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, Official Journal of the European Union L 315/1, 14.11.2012, Can be downloaded at: <http://eur-lex.europa.eu/>

[29] Lombardi P. and Giordano S. *Evaluating the European smart cities visions of the future*. International journal of the analytic hierarchy process. 2012, pp. 27-40.

Europe Direct is a service to help you find answers to your questions about the European Union  
Free phone number (\*): 00 800 6 7 8 9 10 11  
(\* ) Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

A great deal of additional information on the European Union is available on the Internet.  
It can be accessed through the Europa server <http://europa.eu>

### **How to obtain EU publications**

Our publications are available from EU Bookshop (<http://bookshop.europa.eu>),  
where you can place an order with the sales agent of your choice.

The Publications Office has a worldwide network of sales agents.  
You can obtain their contact details by sending a fax to (352) 29 29-42758.

## JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

*Serving society  
Stimulating innovation  
Supporting legislation*

