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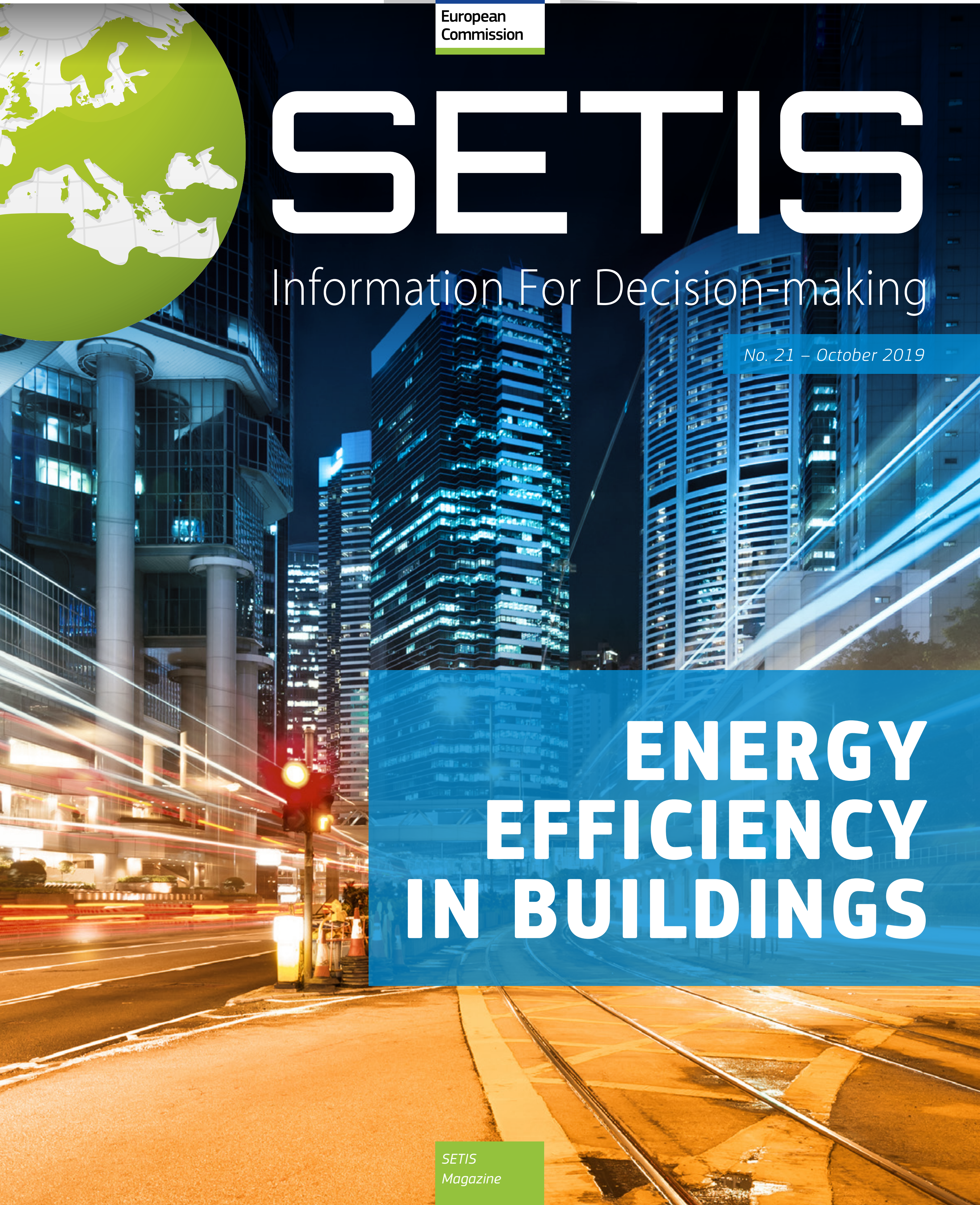

ENERGY EFFICIENCY IN BUILDINGS

SETIS Magazine

SETIS Magazine

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EDITORIAL

Europeans spend approximately 90 % of their time in buildings. Living indoors requires energy to maintain the right temperature, to cook and to use electrical appliances. In fact, energy is expected to guarantee a healthy and comfortable environment. Of all the sectors in Europe, the building sector consumes the most energy, and thus emits the most CO_2.

As a result, policymakers have made buildings a priority in the EU energy policy agenda. They are the focus of the first pillar of the strategic long-term vision for a climate-neutral economy by 2050 (LTS 2050), with a strong emphasis on energy efficiency. Buildings are not only central to the long-term strategy, but they also play an important role in the directives designed to implement it.

Beyond the legislative tools, the European Commission set up the European Strategic Energy Technology Plan (SET Plan) to accelerate the development and deployment of low-carbon technologies. Specifically, under the priority on developing and strengthening energy-efficient systems, buildings play a cross-cutting role across all the actions. They are therefore included in all working groups dealing with renewable heating and cooling.

This edition of SETIS Magazine takes a closer look at the current status of the EU building stock and its future evolution. It discusses the energy transformation of Europe's buildings, along with the challenges and policy actions ahead.

We bring together experts from the research and policy communities to discuss the most relevant and pressing issues on energy efficiency in buildings today. Their input sheds light on the question: What is the potential contribution of buildings in the transition to climate neutrality in 2050?

CONTENTS

The European Strategic Energy Technology Plan (SET Plan) aims to transform the way we produce and use energy in the EU, achieving EU leadership in the development of technological solutions to reach the 2030 energy and climate goals.

The SET Plan, supported by its Strategic Energy Technologies Information System (SETIS), is the key implementing instrument of the European Commission's Energy Union Research and Innovation (R&I) Strategy.

The 12th SET Plan Conference[1] was combined with the European Committee of the Regions Environment, Climate Change and Energy (ENVE) Conference. It took place from 12 to 14 June in Bucharest and focused strongly on the interaction of stakeholders with local and regional authorities on the road towards a clean energy transition. The European R&I community played a key role, discussing common priorities and ways of improving cooperation among public and private stakeholders.

Back to back with the 12th SET Plan Conference, a workshop was organised by SET Plan countries, led by the Finnish representative. It provided a framework for discussing the main challenges to setting up working groups to lead the execution of the endorsed Implementation plans (IPs). This event provided an overview of the current situation and the challenges faced by each working group, such as the complexity of the landscape, the broadness of the sector and financing mechanisms. SET Plan countries outlined the importance of such workshops for keeping track of progress on executing the IPs.

The upcoming 13th SET Plan Conference, 'R&I in the energy sector to enhance European industrial leadership', is being organised by Finland's Presidency of the Council of the European Union and the European Commission. It will take place on 13-15 November 2019 in Helsinki, Finland. The event will address, among other topics, the decarbonisation of industry, sector coupling and developments in renewable energy. Financing of low-carbon technologies, small modular nuclear reactors and the role of women in clean energy transition will also be discussed. Registration open![2]

Having endorsed its 14 IPs[3], the last SET Plan Steering Group (SG) addressed progress made towards a common methodology in several stages: mapping, monitoring and data validation, including agreements on baseline and the templates to be used. The meeting also included an overview of the structure of the working groups for implementing the R&I activities listed in the IPs, which will work collectively to accelerate the clean energy transition in the European Union.

The EU Governance Regulation establishes a new system for the Union and its Member States to plan their energy and climate plans together, in order to fulfil the 2030 targets collectively, delivering the transition towards a climate-neutral Europe by 2050. In this context, a joint meeting took place of the Technical Working Group of the National Energy and Climate Plans (NECPs), the SET Plan SG and the Innovation Fund Expert Group to align the additional efforts of Member States to integrate research, innovation and competitiveness into their NECPs.

1 http://setplan2019.gov.ro/
2 http://setplan2019.fi
3 https://setis.ec.europa.eu/actions-towards-implementing-integrated-SET Plan/implementation-plans

FOREWORD

THE ROLE OF BUILDINGS IN THE LTS 2050

ANDREAS ZUCKER

Andreas Zucker works on long-term energy scenarios with the Economic Analysis and Financial Instruments unit of DG ENER, having previously worked on related topics with the European Commission's science and knowledge service, the Joint Research Centre (JRC). Before joining the European Commission, he worked for two utility companies in areas including corporate strategy, power generation, market analysis and R&I.

Why are buildings important for the Energy transition?

Buildings are responsible for 40 % of the EU's final energy consumption, the highest share. The majority of energy needs – heating & cooling, appliances, water heating and cooking – are still met by fossil fuels. This crucial sector is therefore given particular attention in the European Commission's proposal for a long-term strategy (LTS) on greenhouse gas reductions[1].

What are the options?

The long-term strategy explores a number of measures to reduce energy use and switch to greenhouse gas-(GHG) neutral sources of energy. The continuous renewal of building stock offers an opportunity to improve the thermal insulation of building shells, reducing overall energy demand. Given that about 35 % of the EU's buildings are over 50 years old and almost 75 % were built before energy performance standards existed, renovation must play a key role. By 2050, this will lead to energy savings in the residential sector of 55-62 %.

In addition to reducing overall energy consumption, the fuel mix must become increasingly GHG-neutral. Electrification of the energy system is key, as GHG-neutral energy sources mostly produce electricity. In residential buildings, electricity's share will more than double from today's 25 % to 53-63 %. In tertiary buildings, it will increase to more than 80 %. The electrification of space heating, steered by the prominent use of heat pumps, is an important driver of this dynamic. The 2050 share of electric heating is projected in the LTS to be 22-44 % in the residential sector and 44-60 % in services. Other studies see electricity meeting 35-75 % of residential final heating demand.

These variations reflect great uncertainty regarding future alternatives to electrification. In the LTS, natural gas is, to a large extent, substituted by e-gas in all scenarios, and to a lesser extent by biogas and hydrogen. In other studies, the contribution of natural gas to the energy consumption in buildings ranges from 0 % to over 20 %.

Barriers and enablers

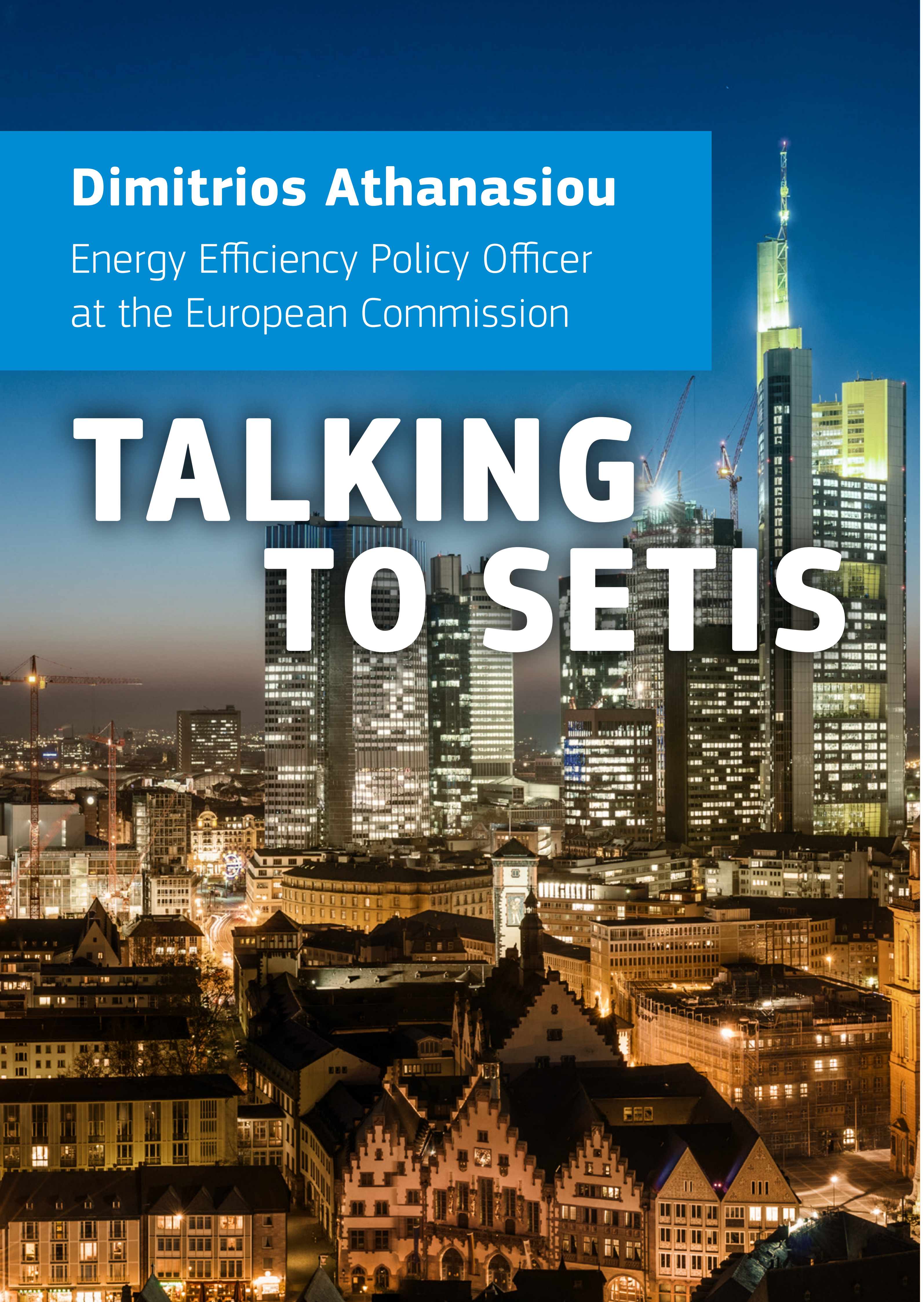
While the fundamental approach is in place, there remain a number of challenges. The pace of renovations must increase significantly: energy-efficient construction solutions, at affordable prices, allow shorter payback times, making renovations accessible to lower-income owners and landlords.

Within buildings, appliances must become ever-more efficient, able to do more with less. A critical development is the 'talk' between appliances (i.e. through the internet of things), laying the foundations for the development of smart buildings.

While there are significant opportunities for energy savings and technological solutions through digitalisation, their uptake will depend on ease of use. Smart technologies – minimally managed on smartphones, for instance – will need to evolve in line with user acceptance.

These are just some of the factors determining the development of energy use in the building sector, a complex and multi-disciplinary field of research and development under the spotlight in this edition of the SETIS magazine.

1 *EC Communication COM/2018/773: A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy*



Dimitrios Athanasiou

Energy Efficiency Policy Officer at the European Commission

TALKING TO SETIS

About the European policy context

Are the targets on decarbonisation and the energy efficiency of EU building stock compatible?

'Decarbonised' building stock is where carbon emissions are brought close to or below zero, by reducing energy needs and ensuring that the remaining needs are met as far as possible by zero-carbon, renewable sources. This approach allows various routes to decarbonisation, taking into account the energy mix, preferences, potential and characteristics of each Member State (MS).

> *Buildings have a crucial role in the long-term strategy by ensuring support to the transition to a smarter, more decentralised, and renewable-intensive energy system*

This strategy is fully aligned with energy efficiency policies and should focus on:

- cumulative targets to retrofit buildings with deep efficiency improvements, in line with national long-term renovation strategies to be established under the *Energy Performance of Buildings Directive (EPBD)*[1];
- strengthening of energy performance standards for new and existing buildings at national or regional level, in line with the EPBD cost-optimal methodology;
- making all new buildings nearly zero-energy;
- replacing fossil fuel use in buildings with decarbonised, renewable electricity and carbon-free fuels.

How connected is the long-term strategy (LTS) with the directives Member States have to follow?

The long-term strategy presents various economy-wide pathways for different scenarios. They include deep changes to our energy system: reduced energy demand; increased electrification; large-scale deployment of renewables; and a significant contribution from new, 'carbon-free' fuels. Buildings play a crucial role in the transition to a smarter, more decentralised, renewable-intensive energy system and, in the longer term, to a climate-neutral economy.

The in-depth analysis[2] supporting the long-term strategy explores various options for the long-term reduction of energy use and associated CO_2 emissions, based on the European regulatory framework for energy efficiency. The analysis includes a holistic review, including performance of building envelope, efficiency of equipment, fuel switch in heating and cooling, smartness in buildings, the uptake of nearly zero-energy buildings and societal and consumer choices.

The long-term strategy, in line with the amended EPBD, highlights the need to increase the rate and depth of renovation, entailing higher investment, and emphasises the importance of buildings automation, control and smart systems (BACS).

The newest recommendation focuses on renovation rates and the gathering of related data by MSs in order to monitor the progress of building stocks. How important is data gathering at this level and what initiatives are being undertaken by the European Commission?

The Evaluation[3] of the EPBD states that there is a lack of reliable and consistent data on European building stock and that there is scope for improvement in order to increase renovation and support decarbonisation.

DIMITRIOS ATHANASIOU

Dimitrios Athanasiou is a Civil Engineer with a Masters Degree in International Construction Management and a Degree from the National School of Public Administration in Greece. He joined the European Commission three years ago as a policy officer in the Buildings Team of the Energy Efficiency Unit in DG Energy. His work focuses on the implementation of the Energy Performance of Buildings Directive, and in particular the monitoring of calculation methodologies and nearly zero-energy buildings uptake within the EU. Prior to joining the European Commission he worked as a Minister's Consultant on energy efficiency in the Hellenic Ministry of Environment and Energy, and in civil engineering.

1 *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings*
2 *European Commission in-depth analysis in support of the EC Communication COM(2018) 773 'Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy'*
3 *EC Staff Working Document, SWD(2016) 408 final: Evaluation of Directive 2010/31/EU on the energy performance of buildings*

Increasing the rate, quality and effectiveness of the renovation of existing buildings is the biggest challenge for the coming decades. For that reason, the revision of the Directive[4] introduces a requirement for Member States to establish comprehensive long-term strategies for a highly efficient and decarbonised building stock by 2050 and a cost-effective transformation of existing stock into nearly zero-energy buildings. These long-term strategies must provide a national overview of building stocks and include a roadmap with specific measures, measurable progress indicators and indicative milestones for 2030, 2040 and 2050. The revision makes stronger reference to energy poverty and includes health, safety and air quality, alongside initiatives to promote smart technologies, skills and education, and policies targeting the worst performing buildings, split-incentive dilemmas, market failures and public buildings.

More transparent information on building stocks will better inform policymakers and support the decisions of market players, in particular financial institutions, a necessary precondition to improving the depth and rate of renovation.

Within that framework, the EC has set up the EU Building Stock Observatory[5], with two primary objectives: (i) to provide a snapshot of the energy performance of EU building stock with high quality and comparable data from all MSs, and (ii) to set a framework and methodology for the continuous monitoring of building stock.

A specific study has also been undertaken to define and collect data on building renovation, and on the uptake of nearly zero-energy buildings.

The European Commission is also exploring the use of big data. This is an opportunity to address data gaps and limitations, and to create value by identifying low performing buildings, along with the improvements likely to lead to significant savings.

Finally, the European Commission is looking into further actions to strengthen Energy performance certificates (EPC), including EPC databases as a tool for finance mobilisation and for monitoring the energy performance of building stocks.

4 *Amending Directive (EU) 2018/844 of the European Parliament and of the Council (2018) amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency*

5 https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/eubuildings

ARTICLE

The role of buildings in the heating sector transition

In Europe, and worldwide, buildings and their related services are responsible for a large share of the total final energy consumption, therefore also for the environmental problems which ensue[1,2]. Serrano et al. 2017[3] showed that while the main driver for energy consumption in residential buildings in Europe is the specific energy consumption, this is decreasing due to various technological options and European policies[4]. Other drivers, such as the residential floor area per person and the number in each household, are increasing. This suggests that efforts to reduce energy consumption in buildings should focus not just on the energy efficiency of household appliances[5] heating, ventilation and air conditioning (HVAC) systems and other appliances such as refrigerators) but also on embedded energy. According to Ürge-Vorsatz et al. 2013[6], when a building is constructed or retrofitted to a given energy efficiency level, it becomes extremely uneconomic to carry out a new energy retrofit until the next construction cycle. In buildings the lock-in effect is therefore high, and should always be kept in mind.

> *To increase the energy efficiency of buildings, the first strategy is the renovation of their envelopes*

The heating and cooling sector in Europe is still highly based on fossil fuels (75 % of the fuel is non-renewable), although it is moving towards clean, low-carbon energy sources (renewable energy sources)[7]. The heating and

1 https://iea.org/topics/energyefficiency/buildings/

2 D. Ürge-Vorsatz, L.F. Cabeza, S. Serrano, C. Barreneche, K. Petrichenko, *Heating and cooling energy trends and drivers in buildings*, Renewable and Sustainable Energy Reviews, 41, 2015, pp. 85-98.

3 S. Serrano, D. Ürge-Vorsatz, C. Barreneche, A. Palacios, L.F. Cabeza, *Heating and cooling energy trends and drivers in Europe*, Energy 119, 2017, pp. 425-434.

4 *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings*. The original directive is *Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings*

5 https://ec.europa.eu/energy/en/topics/energy-efficiency

6 D. Ürge-Vorsatz, K. Petrichenko, M. Staniec, J. Eom, *Energy use in buildings in a long-term perspective*, Current Opinion in Environmental Sustainability 5, 2013, pp. 141-151.

7 *EC Communication COM(2016) 51, An EU Strategy on Heating and Cooling*

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cooling sector spans buildings (45 %), industry (37 %) and services (18 %); the heating sector transition is therefore closely linked to the decarbonisation of buildings. This relationship is explored further in studies of specific cases in Switzerland[8], Germany[9], and Finland[10]. Various strategies can be employed to achieve decarbonisation, as outlined below.

> *After improving building envelopes, the next step in the decarbonisation of the building sector is the use of renewable energy to provide the required energy services*

The first strategy is the renovation of building stock by increasing the energy efficiency of the building itself (walls, roof, windows, etc.). This would reduce energy demand, which, as mentioned above, is key to achieving EU targets. When this renovation is designed, the materials selection should take into account the embedded energy and their whole life cycle[11]; this is especially important in the case of insulation[12]. Windows and doors should of course be designed to minimise infiltrations.

The next step in the decarbonisation of the building sector is the use of renewable energy to provide energy services. For heating, the renewable energies to use are solar thermal, geothermal, and biomass, but renewable electricity is also an option when using heat pumps to heat buildings[13]. Moreover, district heating, especially if fed with renewable sources, is a good option. Again, the lifecycle of products should be taken into account, a point included in the circular economy strategy[14].

Buildings can therefore contribute strongly to the transition of the heating sector in two ways. The first is the decarbonisation of building stock though renovation, specially upgrading the building envelope using materials with low embodied energy and ensuring less energy demand. The second is the integration of renewable energy sources in buildings to provide heating and cooling.

8 K. Narula, J. Chambers, K.N. Streicher, M.K. Patel, *Strategies for decarbonising the Swiss heating system*, Energy 169, 2019, pp. 1119-1131.
9 E. Merkel, R. McKenna, D. Fehrenbach, W. Fichtner, *A model-based assessment of climate and energy targets for the German residential heat system*, Journal of Cleaner Production 142, 2017, pp. 3151-3173.
10 K. Dahal, S. Juhola, J. Niemelä, *The role of renewable energy policies for carbon neutrality in Helsinki Metropolitan area*, Sustainable Cities and Society 40, 2018, pp. 222-232.
11 M.N. Nwodo, C.J. Anumba, *A review of life cycle assessment of buildings using a systematic approach*, Building and Environment 162, 2019, pp, 106-290.
12 A. Vilches, A. Garcia-Martinez, B. Sanchez-Montañes, *Life cycle assessment (LCA) of building refurbishment: A literature review*, Energy and Buildings 135, 2017, pp. 286-301.
13 S. Puri, A.T.D. Perera, D. Mauree, S. Coccolo, L. Delannoy, J.L. Scartezzini, *The role of distributed energy systems in European energy transition*, Energy Procedia 159, 2019, pp. 286-291.
14 https://ec.europa.eu/environment/circular-economy/index_en.htm

ARTICLE

Cost-effective transformation of Italian building stock

The energy efficiency of buildings is currently one of the most important topics of debate at international level. The European Union has promoted programmes, projects and directives to develop harmonised instruments, criteria and solutions to increase the energy efficiency of both new and existing buildings. The main reference legislation in this field includes *Directive 2010/31/EU* on building energy performance and *Directive 2012/27/EU* on energy efficiency, along with their subsequent amendments.

Building energy efficiency is a priority objective for Italy. Relevant regulations and incentive measures include:

- Legislative Decree 192/2005, updated by Law 90/2013, transposing Directive 2010/31/EU;
- Inter-ministerial Decree 26 June 2015, enforcing Legislative Decree 192/2005, and subsequent amendments, providing minimum energy performance requirements for buildings and guidelines for building energy performance certification;
- Legislative Decree 102/2014 and subsequent amendments, transposing Directive 2012/27/EU.

According to the *Italian Energy Efficiency Action Plan (PAEE 2017)*[1], the overall final energy saving achieved in 2016 by the civil sector was about 38.2 TWh/year[2], equal to 67 % of the target expected in 2020. The residential sector has already reached 84 % of the final target, while the tertiary sector, at 15 %, still has far to go. The *Italian National Energy Strategy of 2017 (SEN 2017)*[3] recently established a programme to meet the European goals by 2030, aiming for industrial leadership to capture the great international growth of efficient technologies. For the residential and tertiary sectors, SEN 2017 set a target to reduce the final energy consumption by 58.2 TWh/year[2] by 2030 compared with 2015.

According to the last national census of 2011, Italian building stock comprises 14.5 million buildings, of which 84 % are residential. More than 60 % of residential buildings were built before 1976, i.e. before the introduction of the first law on energy saving. The annual final energy use of the civil sector covers about 43 % of national overall energy use. On average, the annual thermal energy consumption[4] is 125÷142 kWh/m^2 for residential buildings, 170 kWh/m^2 for office buildings, and 130 kWh/m^2 for schools.

1 *Italian Energy Efficiency Action Plan (PAEE)*, Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Rome, 2017.
2 1 Mtoe = 11.63 TWh
3 *National Energy Strategy (SEN)*, Italian Ministry of the Economic Development and Ministry of the Environment, Rome, 2017.
4 *Italian Strategy for the Energy Refurbishment of the National Building Stock (STREPIN)*, Italian Ministry of Economic Development and Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Rome, 2015.

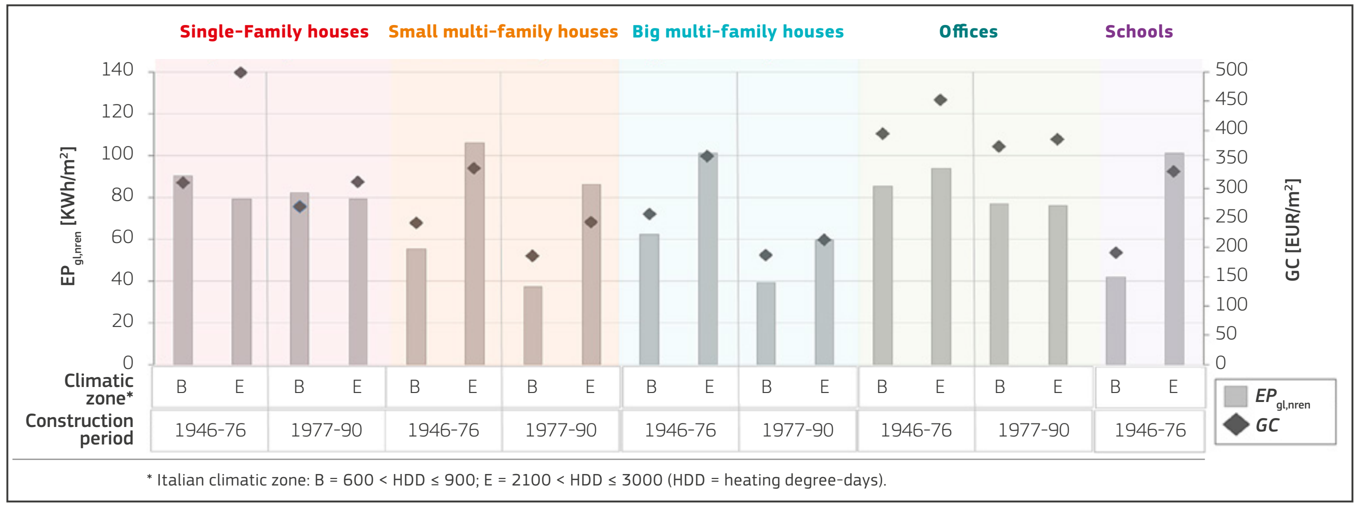

Figure 1 – Global cost and energy performance of cost-optimal energy efficiency measures implemented in Italian reference buildings. Source: MiSE[5].

Building typology	Refurbished building floor area [10^6 m²/year]	Energy saving by 2020 [TWh/year][2]	Investment cost [10^9 EUR/year]
Residential	170	48.9	24.1
Non-residential	16	17.3	17.5
Total	186	66.2	41.6

Table 1 – Energy refurbishment scenario of Italian building stock - period 2014-2020. Source: STREPIN[4].

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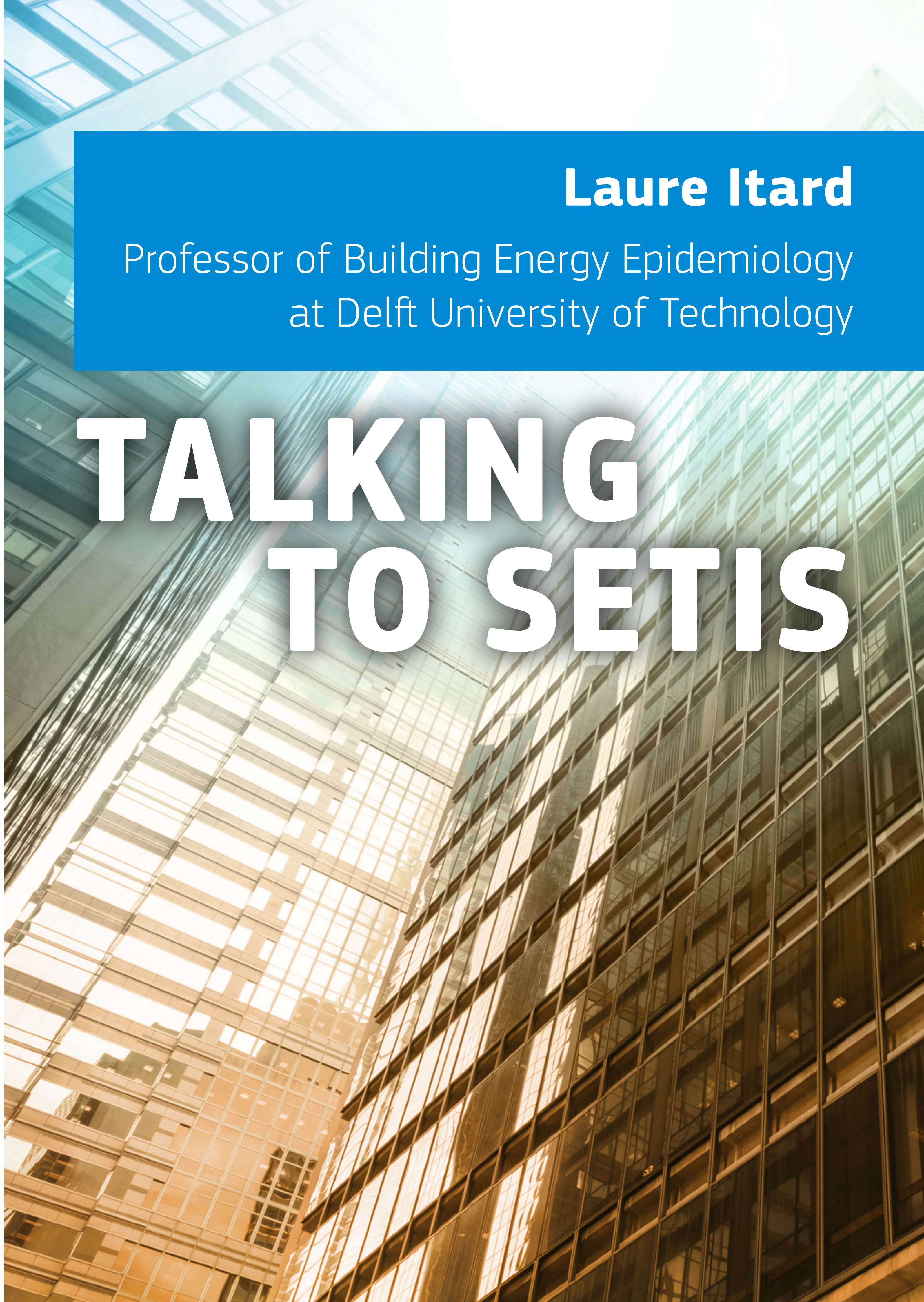
Vincenzo Corrado is a civil engineer and Full Professor of Building physics and building energy systems at Politecnico di Torino, where he is vice-coordinator of the academic board of Building Engineering and coordinates a unit of TEBE (Technology Energy Building Environment) Research Group, focused on building thermo-physics, building energy modelling, procedures for energy audit and certification, indoor environmental comfort, legislation and technical standards. He is a former President of IBPSA-Italy (Italian chapter of the International Building Performance Simulation Association), Italian delegate of CEN/TC 89 (Thermal performance of buildings and building components) and of ISO/TC 163 (Thermal performance and energy use in the built environment).

The energy-saving potential of Italian building stock is therefore significant, and mostly achievable through energy refurbishment measures with low payback periods. The national application of the comparative methodology framework, in compliance with *Directive 2010/31/EU* - Art. 5, allowed the identification of cost-optimal energy efficiency measures for major renovation of buildings. The resulting global cost (GC) in 30 years building lifecycle and the related overall non-renewable energy performance (EPgl,nren) for the analysed reference buildings are shown in Figure 1.

The Italian Strategy for the Energy Refurbishment of the National Building Stock (STREPIN 2015)[3] provides an energy refurbishment scenario which takes into account current minimum energy performance requirements for the building envelope and technical building systems, technical feasibility and a favourable cost-benefit ratio. The resulting energy-saving potential in the period 2014-2020 amounts to 66.17 TWh/year[2], whereas the overall investment costs are equal to EUR 41.6 billion/year, as shown in detail in Table 1.

Although the energy-saving potential is high, several barriers hinder its full achievement. Instruments and actions to overcome these barriers were identified in SEN 2017, such as, for the civil sector, the reinforcement of minimum requirements and regulations, the extension of incentives (e.g. tax deductions), and the introduction of direct financial incentives for retrofit actions in public buildings.

5 Updating of the application of the calculation methodology to derive cost-optimal energy performance requirements (2010/31/EU Directive, Art. 5), Italian Ministry of Economic Development (MiSE), Rome (in Italian).



Laure Itard

Professor of Building Energy Epidemiology at Delft University of Technology

TALKING TO SETIS

About renovation

Energy use in buildings is a main contributor to the depletion of natural resources and responsible for numerous emissions affecting the quality of global, regional, local and indoor environments. As new-build rates are very low (and with regard to circularity should be kept as low as possible), the vast majority of future building stock has already been built and the main challenge is to increase its energy efficiency, both by decreasing its energy demand and by deploying renewable energy conversion systems.

Two main developments are rapidly changing today's (research) landscape.First, the complexity of buildings' energy systems has increased a lot and is still increasing. On the one hand, this is a consequence of the on-going transition from either autonomous local systems (e.g. a home boiler) or strongly centralised systems (e.g. a power plant or district heating) to distributed systems in which nodes (e.g. buildings) act as both supplier and consumer, leading to the so-called smart electrical and thermal grids. On the other hand, this increase in complexity relates strongly to the needs for multiple integrated conversion, distribution and buffering systems inherent to the use of renewable energy.

> *Energy management systems (BEMS) are becoming a necessary part of buildings' energy systems*

Second, the fast growing availability of cheaper sensors, smart meters, building management systems, cloud and internet of things frees up huge potential for feedback on actual operational performance, useful for theoptimisation and design of systems, as well as for the monitoring of energy policies. While a couple of years ago direct energy monitoring was still considered too costly, it is now starting to be recognised as a main component of energy efficiency. However, the more data we have, the more the lack of suitable analysis methods becomes burdensome. Unlike industrial systems, buildings' energy systems work in strong interaction with the building and its occupants, are essentially variable partial load systems and are also responsible for the quality of the indoor climate, making multi-objective performance analysis a must. However, the use of data analytics for system optimisation is still in its infancy.

> *Quickly growing availability of smart meters frees a huge potential for feedback on actual operational performances of buildings and the monitoring of energy policies*

The recent development of new methods for the assessment of the effectiveness of energy policies at building stock level, using actual energy data, has led to the discovery of huge discrepancies between modelled and actual values of energy consumption and energy-saving potentials in the Dutch residential sector, findings that were later reported in other countries, leading recently to the foundation by the International Energy Agency of IEA-EBC-Annex 70, '*Building energy epidemiology*'.

However, while these data-mining activities based on statistical approaches led to numerous new insights, they do not allow for a better understanding of the causes of the discrepancies between models and reality, nor for the understanding of the complex relationships between energy system, building system and occupant behaviour. This understanding, however, is a necessity when it comes to the realisation of energy-saving measures, the transition to sustainable systems and demand/supply matching in smart grids. To study these complex relationships and causalities, much more detailed and specific monitoring is needed. In the past, monitoring activities were always carried out at the level of labs, climate chambers or at single project level, making the extrapolation of the results to building stock impossible and leading to a bias in behavioural aspects as people being observed under lab circumstances are likely to behave in a completely different way than in a familiar home or office environment. That is why large monitoring campaigns in dwellings in use, using a sensor-rich measurement environment, are necessary. This fits very well with the trend of home automation and internet of things, and would allow for the study of the huge possibilities of data-driven modelling and machine learning for automated inspection of buildings and automated energy-saving recommendations per household.

There are more developments in energy management and building automation systems in non-residential buildings because there are more incentives for maintaining a continuous high level of indoor comfort as it relates to productivity. The heating, ventilation and air conditioning (HVAC) systems in this sector have therefore become very complex, also due to developments in the field of commissioning and energy-performance contracting and to the increased use of renewables like geothermal energy. Consequently, building and energy management systems (BEMS) are becoming a necessary part of buildings' energy systems. Where buildings have been equipped with multiple sensors, these BEMS deliver an enormous amount of data, the potential of which is currently largely unexploited. Here, too, there is a need to develop analysis methods, entailing combinations of statistics with thermodynamic models, control models, systems dynamics' theory and expert systems and to develop diagnosis and optimisation methods. Diverse studies have shown that by applying continuous energy diagnoses methods, 10-30 % energy savings could be achieved. That's well worth doing.

LAURE ITARD

Laure Itard is Professor of Building Energy Epidemiology at Delft University of Technology. From 2010 to 2017 she was Professor of Applied Sciences at The Hague University of Applied Sciences, research group Energy in the Built Environment. Previously, she was a researcher at DUT and a consulting engineer at Deerns in the field of energy and buildings. Her field of expertise spans energy modelling in buildings, data-driven energy policies, (big & smart) data analysis, statistics, building stock energy models, Energy performance of buildings Directive (EPBD), fault diagnosis models, heating, ventilation & air conditioning systems (HVAC), thermal comfort and post-occupancy evaluation.

ARTICLE

Smart buildings and the role of digitalisation

Digitalisation is the innovative use of information and communications technologies (ICT), in particular the large-scale rollout of smart devices and sensors, and the use of big data collection and analysis. A recent Joint Research Centre report[1] provides real-world examples of its potential for heating and cooling in buildings and highlights key policy initiatives and research projects.

> *Digitalisation will enable energy communities, helping them to manage and control their assets*

Digitalisation: Opportunities for heating and cooling shows that digitalisation optimises operations, planning and business models, and connects producers of heat and cooling, users, local stakeholders and energy markets. It contributes to changes in energy market design and is a driver of smart buildings, smart communities, smart cities, distributed energy, and district heating and cooling (DHC).

At the design stage, a growing number of simulation tools is available to improve understanding of the interaction of the building components that contribute to energy demand. Building information modelling creates a '*digital twin*' of the entire building with all its systems.

Regular feedback, for example via in-house displays, is a low-cost first step. However, it is hard to engage households in energy issues, especially if the information received is not clear, action-oriented and frequent. The revised Energy Efficiency Directive (EED)[2] lays down new and strengthened rules on billing and consumption information. But there are few systems on the market that go beyond basic information and visualisation to carry out advanced analytics.

Building energy management systems (BEMS) combine software with smart thermostats and sensors to anticipate behaviour, and use weather forecasts and energy prices to predict demand and manage heating and cooling. The aim is to optimise energy consumption and maintenance, enable demand response, and improve comfort and environmental quality. Improvements in sensors and controls, and the use of computers, have made BEMS more sophisticated and less expensive. Systems can be linked, for example by using sensors embedded in lighting to tailor heating and cooling, and managed by algorithms or by users themselves. Artificial intelligence (AI) can greatly enhance their potential by balancing energy saving and user-customised comfort.

1 Lyons, L., *Digitalisation: Opportunities for Heating and Cooling*, EUR 29702 EN, Publications Office of the European Union, Luxembourg, 2019

2 Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency

As regards individual items of equipment, air conditioning, for example, can be improved using variable-speed drives and optimised controls. Other relevant technologies include switchable vacuum-insulated panels, switchable mirror film on windows, automatic shades, and integrated cooling of equipment.

> *There will be many benefits to digitalising and decarbonising heating and cooling: energy savings, reduced operating costs and fuel bills, better service quality, new markets for local heat, job creation, industrial competitiveness, improved air quality, etc.*

At district level, networks can become more efficient, intelligent and cheaper thanks to digital technologies that enable data management relating to temperatures, flows, pressure and leaks. Under the revised EED, meters in DHC networks will soon have to be remotely readable. While this was introduced to provide better consumption information to customers, it will also open up optimisation opportunities for network operators. Smart network controllers would enable more dynamic control of temperatures, which would reduce heat loss and therefore primary energy demand. Buildings would communicate with each other and with energy production and distribution systems about which sources are available, making the system more efficient over time. Digitalisation would also enable better co-operation with service providers and equipment manufacturers.

Going one step further, smart energy systems co-ordinate electricity, heat and gas networks to achieve an optimal solution for each individual sector as well as the overall system. Again, the large volumes of data produced by smart meters and other digital technologies could be used to predict heating and cooling flows, spot inconsistencies and check for leaks or losses. In addition, AI could control distributed production assets to optimise local resources and minimise overall cost.

From the perspective of businesses, digitalisation of heating and cooling was initially driven by a simple business case to reduce costs. In future, it will be driven more by revenue streams from new services and customisation. At the same time, digitalisation will enable energy communities, helping them to manage and control their assets. Digitalisation is also a potential way to reduce the cost of Nearly Zero Energy Buildings by shifting the focus from individual buildings to entire settlements.

There will be many benefits to digitalising and decarbonising heating and cooling: energy savings, reduced operating costs and fuel bills, better service quality, new markets for local heat, job creation, industrial competitiveness, improved air quality, etc. However, energy savings might not be as large as expected, for example due to the energy consumption of digital technologies themselves, and there will also be destabilising effects in areas such as privacy, cybersecurity and the digital divide.

New policies – both energy and digital – could mitigate those downsides and ensure that the best technologies and business models prevail. The Clean Energy for All Europeans package and the revised Energy Performance of Buildings Directive are steps in this direction. Continued support for R&I, as well as for the development of new business models and standards, is also needed.

LORCAN LYONS

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ARTICLE

Building energy epidemiology as a tool to support European building energy performance improvement

What does the transition towards low-carbon building stock mean for Europe?

European building stock is responsible for around a third of CO_2 emissions, and the EU has set a target of 20 % reduction by 2020 and 60 % by 2030, from a 1990 baseline. Meeting these targets means focusing on decarbonising the power supply and making concerted efforts to reduce energy demand through retrofits of existing stock.

> *Building energy epidemiology is the study of energy demands to improve our understanding of variations in the energy-consuming population, and their causes*

Under the *Energy performance of buildings Directive*[1], Member States must outline specific actions to deliver these reductions across their building stock. For many, this means devising programmes that provide support and financial incentives to carry out energy performance audits and refurbishments. The question that must be addressed is: what policies and actions will deliver these results?

Policies are developed in a complex environment of crosscutting multi-objective and interacting issues, including the climate crisis, energy markets, development and building controls, and socio-economic pressures. European building stock is not simple: a heterogeneous population of buildings in terms of design, construction, uses and users across a diverse political and climatic geography. The tools and systems necessary for such a large-scale assessment are lacking, as is a general understanding of the characteristics which affect energy performance.

What is energy building epidemiology and how can it help the energy efficiency of building stock?

To achieve such large-scale change, it makes sense to use existing methods, tools and practices for targeting and testing interventions among populations. One such field is epidemiology. Building energy epidemiology is the study of energy demands to improve our understanding of variations in the energy-consuming population, and their causes. It considers the complex interactions between physical and engineered systems, socio-economic and environmental conditions, and the individual practices of occupants.

1 *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings*

Energy epidemiology provides an over-arching approach, where findings from large-scale studies inform energy policy, and provide the context for conventional small-scale studies and information for predictive models.

Building energy epidemiology is being taken up by many European researchers through Annex 70: Building energy epidemiology[2] under the International Energy Agency's (IEA) technology collaboration partnership within Energy in buildings and communities. Annex 70 is an international collaboration of researchers, industry and government from across the globe who are working to develop methods to improve empirical evidence on energy demand in building stock.

How can analyses of building stocks at scale help policymaking?

Being able to identify the spread and level of energy demand and performance across building stock reveals the scale of the challenge and offers a general '*health check*'. Being able to further determine the factors that influence energy performance, and devise and test retrofit treatment strategies based on a working knowledge of their real performance, is fundamental to meeting the targets.

> *In the UK, the use of a National energy efficiency data-framework has yielded considerable benefit for policymakers in evaluating the impact of retrofit programmes on energy use*

Developing a system for consistent data collection and review will help policymakers understand how building characteristics, and people's behaviours and needs, drive energy use. This will help to improve the energy performance gap – the difference between models used to plan retrofits, and subsequent real-world measurements.

Such a system of information collection and analysis will also allow policymakers to better understand the intended and unintended consequences of their programmes. For example, a retrofit package will impact differently on households living with fuel poverty than those which are not.

IAN HAMILTON

Ian Hamilton is an Associate Professor at the UCL Energy Institute, University College London, UK. Ian's research is focused on the nexus between energy supply-demand in buildings, indoor and urban environmental conditions, and health and climate change. Ian is the Principle Investigator for the IEA's 'Annex 70: Building energy epidemiology' on energy and building stock data and modelling, drawing together researchers from 25 institutions across 12 countries. Ian is a co-investigator on the UK's 'Centre on Research for Energy Demand Solutions', the UK-China Centre for Total Building Performance and the UK's Health Protection Research Unit on 'Healthy and Sustainable Cities under Climate Change'.

Are there best practices in national building stock monitoring and how can we apply them more widely?

Routine data collection on energy efficiency retrofits is lacking across Europe. Many authorities report processes for changes made to buildings – e.g. land valuation and taxation, building controls, and energy performance certificates (EPCs) – but few have the data for population level, epidemiological studies. EPCs are helpful but there are issues with how these certificates are designed and implemented.

However, some initiatives are beginning to yield improved empirical analysis, helping to target and evaluate energy performance investments. EPC data are publicly available in some countries (UK, Ireland, Netherlands, Denmark, Sweden, Norway), providing a degree of transparency and a detection mechanism, though they still need to be improved in terms of quality. In Ireland, the approach to information collection for the EPC[3] is highly focused on quality of information and the assessor's ability to provide advice for future investment in energy performance.

What policy initiatives have produced positive results in the UK?

In the UK, the practice of using of large, federated databases, such as the National Energy Efficiency Data-Framework[4], has improved the understanding of the real-world (i.e. empirically measured) impacts of large-scale retrofit programmes. Analysis of energy supplier obligations found that some retrofits were not achieving what the models had estimated (Hamilton et al, 2013[5]; Hamilton et al 2017[6]).

In the UK, the use of NEED has yielded considerable benefit for policymakers in evaluating the impact of retrofit programmes on energy use[7], helping to target energy poverty programmes such as the Energy Company Obligation and the Warm Homes Discount.

2 https://energyepidemiology.org/
3 https://finance-ni.gov.uk/articles/energy-assessors-and-accreditation-schemes
4 https://gov.uk/government/collections/national-energy-efficiency-data-need-framework
5 https://sciencedirect.com/science/article/pii/S0301421513002413
6 https://sciencedirect.com/science/article/pii/S0378778817310940
7 https://gov.uk/government/collections/household-energy-efficiency-national-statistics

ARTICLE

A Swedish perspective on energy communities and districts

Carbon neutrality in the building sector requires minimum and flexible demands on energy and materials, as well as the integration of renewable energy sources. Whereas in individual buildings, minimum demand is achieved with active and passive efficiency measures in combination with comfort flexibility and increased tolerance to automated management, approaches at district level allow for additional synergies key to carbon neutrality.

> *With the proper upscaling mechanisms, districts can be catalysts of innovative solutions*

The Swedish building sector and energy system are quite particular. Existing buildings perform relatively well and the energy system relies largely on low-carbon energy generation – the predominance of district heating and clean electricity. The Swedish government aims for carbon neutrality by 2045, and roadmaps are being designed to achieve this target. The total energy use in buildings should decrease by 20 % by 2020 and 50 % by 2050, from a 1995 baseline[1]. As substantial growth is expected around the biggest urban areas, with 705 000 dwellings to be built by 2025[2], these goals are even more challenging. In this context, the examples below are key to establishing a market for solutions for very low carbon buildings and thus, meeting environmental, social and economic targets.

Comprehensive urban regeneration

CITIFyED project[3] has renovated an area of 379 rental apartments in Lund. Beyond improving energy efficiency, measures were taken to prevent a large rent increase: a broader urban retrofit of the area with densification projects, retrofitting and modernisation, including new passive houses, and a renewed town square. Communication activities from the early stages increased social acceptance.

Local heat recovery

An energy system of a community of mixed uses can provide positive demand-supply synergies. For instance, 1.2 EJ/year[4] are potentially available for recovery from urban heat sources in the EU. This corresponds to more than 10 % of the EU's total energy demand for heat and hot water. ReUseHeat Project demonstrates the techno-economic viability of urban heat recovery, e.g from data centres, metro ventilation or cooling systems. A techno-economic assessment[5] shows that the availability of urban excess heat exceeds what is cost-efficient to use. Issues regarding contracts, business models and barriers to investment have been identified in interviews with stakeholders[6].

> *Projects at district level present an outstanding opportunity to develop and test the solutions for very low carbon buildings that are required to achieve the ambitious environmental targets*

Heat supply to new low-energy building areas

Three options exist for heat supply in new construction: '*individual*', '*on-site*' and '*large heat network*'. A study drawing on real data in Sweden[7] shows that the individual and on-site options increase biomass and electricity use, which in turn increases carbon emissions in a broader systems perspective. The impact of the large heat network option depends on the scale and supply-technologies of the district heating system. A cost assessment[8] shows that in most cases, the large heat network has the lowest system cost.

Sharing facilities

Many premises lend themselves to sharing, such as canteens, receptions and storage facilities. An estimation[9] of the potential for sharing office spaces shows that energy demand for heating could be reduced by 35-75 %, and electricity use by 41-57 %, resulting in correspondingly substantial CO_2 emission reductions. Additionally, the reduction in floor area implies a substantial reduction in the energy need and associated emissions from the construction of new office buildings. In a residential community, sharing can be extended to laundry spaces, hobby rooms, libraries and rental rooms for family guests, allowing for smaller apartments.

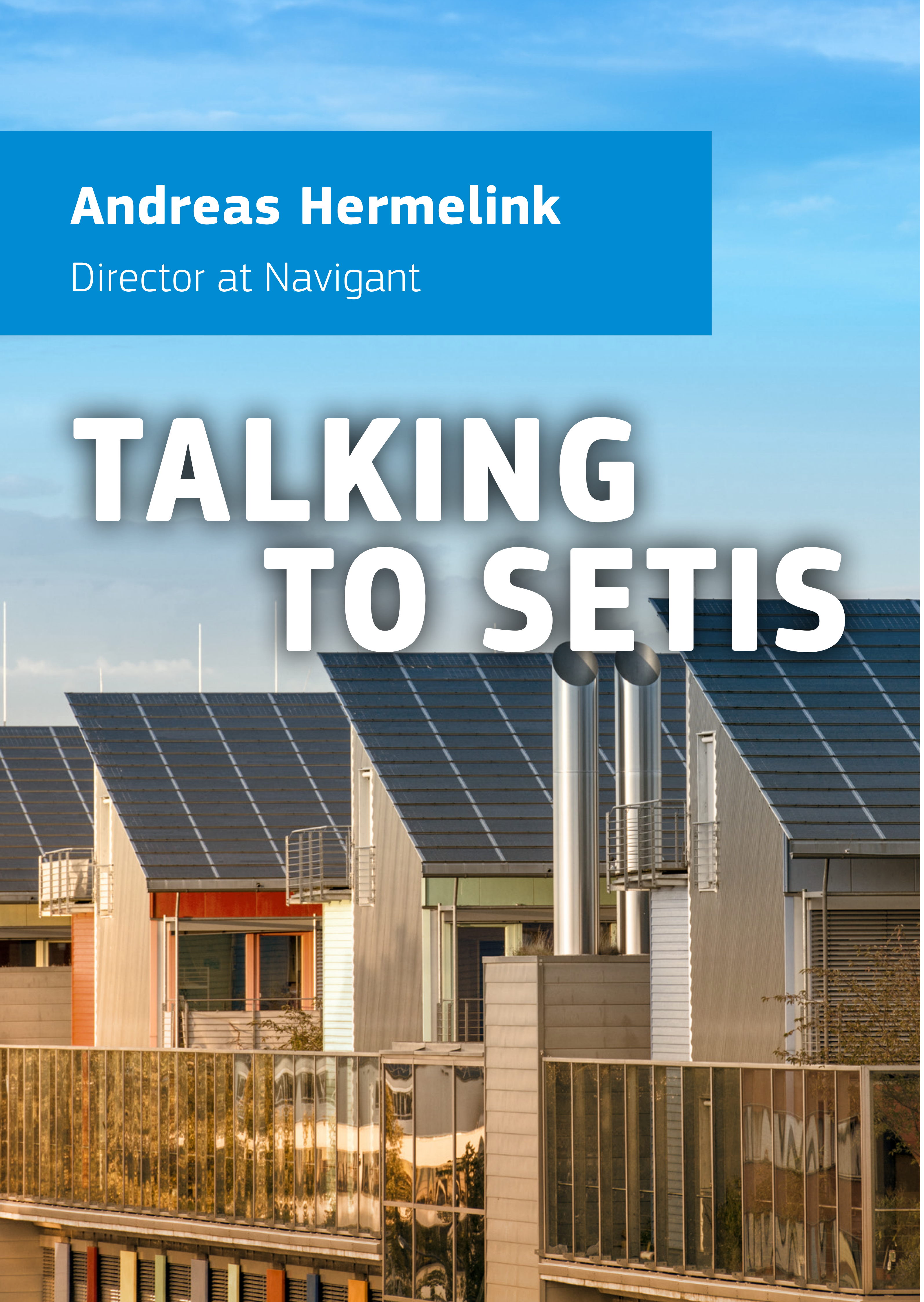
Networks for reusing construction products

The construction industry in Sweden creates a waste stream of about 10 million t/year. There is national potential to reduce waste volumes by 18 000 t/year, greenhouse gas emissions by 21 000 tCO_2e, and purchasing costs by around EUR 60 million/year by reusing existing interior construction products in conjunction with office renovations. A recent study[10] shows that local networks are central to mapping, storing and relocating used construction material. Incentives should be aligned with the EU waste hierarchy. The property owner is seen as a key stakeholder, with the opportunity to create and spread incentives for reuse.

ERIKA MATA

Dr. Erika Mata is a researcher in the Unit for Climate & Sustainable Cities at the IVL Swedish Environmental Research Institute in Gothenburg. She has worked internationally as architect, energy consultant and researcher, on the transformation of the building sector to meet environmental, economic and social targets, with a focus on climate impact. She has been project leader, WP leader and researcher in numerous national and international research projects with various geographical boundaries, aggregation levels and topics (models and data, building retrofitting, demand and supply side, effects of future climate change, policy). She is currently Lead Author for Chapter 9 Buildings of the Working Group III contribution to the 6th Assessment Report of the Intergovernmental Panel on Climate Change.

1 *Government Bill 2005/06:145: National programme for energy efficiency and energy-smart construction*, Ministry of Sustainable Development, 2006. https://government.se/
2 *Four Futures: The Swedish energy system beyond 2020*, Swedish Energy Agency, 2016.
3 *Information Package nr 10: The Linero demonstration site.* http://cityfied.eu/
4 *D1.4 Accessible Urban Waste Heat.* https://reuseheat.eu
5 *D1.6 Scenarios for urban excess heat exploitation.* https://reuseheat.eu
6 K. Lygnerud, et al., *Contracts, Business Models and Barriers to Investing in Low Temperature District Heating Projects*, Applied Sciences, 2019.
7 A. Fakhri Sandvall, et al., *Low-energy buildings heat supply–modelling of energy systems and carbon emissions impacts*, Energy Policy 111, 2017, pp. 371–382.
8 A. Fakhri Sandvall, et al., *Cost-efficiency of urban heating strategies – Modelling scale effects of low-energy building heat supply*, Energy Strategy Reviews 18, 2017, pp. 212 – 223.
9 L. Fjellander, et al., *Delningens potential; Rapport C371.* https://resource-sip.se
10 H. Gerhardsson, et al., *Arbetssätt för ökat återbruk i lokalanpassningar; Rapport B 2351.* https://ivl.se



Andreas Hermelink

Director at Navigant

TALKING TO SETIS

About Nearly zero-energy buildings

What is the concept of NZEB?

Let's look at the EPBD: 'Nearly zero-energy buildings (NZEB)' means a building that has a very high energy performance… The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources.'

A meaningful interpretation should start with why we need NZEBs. We spend 80-90 % of our time in buildings. Every building should provide adequate comfort, so this basic requirement must be met by NZEBs too. Energy-related benchmarks for all buildings, not just NZEBs, should be based on quantified comfort levels to make things comparable.

Luckily, a well-designed NZEB can easily reach very high levels of comfort. Thus, we can move on to '*high-energy performance*'. Most buildings we build or renovate today won't get major updates to their energy performance till 2050. This is why NZEBs should mirror long-term climate and sustainability targets in their '*very high-energy performance*'. In the context of the Intergovernmental panel on climate change (IPCC)[1] special report on 1.5 °C, a responsible NZEB definition must mean zero, not just 'nearly' zero emissions.

Moreover, a NZEB must be a useful part of a fully decarbonised energy system, i.e. by 2050, should be supplied by 100 % renewable energy, which obviously gets easier with very low energy need or use. There should be very low limits for the energy need for heating, cooling, and domestic hot water to achieve the comfort levels above, or for the energy use of its technical building systems. This provides flexibility to the energy system and frees up renewable energy for other sectors like transport. In most building types, the total energy need for heating and cooling could easily be limited to (significantly) below 30 kWh/m^2a. Many NZEB definitions have lower aspirations.

Smart rather than '*high-tech*' design is needed to achieve such efficiency cost-effectively.

How far can we go by 2050 in transforming EU building stock into NZEBs as expressed in the EPBD?

The latest update of the EPBD explicitly asks Member States to '*ensure that long-term renovation strategies deliver the necessary progress towards the transformation of existing buildings into early zero-energy buildings*'. Yet, current renovation rates and depths are way below that aspiration. Implementing the EPBD requirement is not just a moral obligation to current and future generations, but also makes good business sense for Member States and the EU. To fully utilise the economic potential of NZEBs at minimum cost, Member States should see building stock as one element of an overall energy system that needs to interact and exploit synergies with other sectors like industry and transport.

What role should MSs play in the transformation of building stock?

Member States should take on the EPBD's mandate and immediately create and implement science-based, long-term renovation strategies. A well-balanced policy mix of regulations, incentives, information and capacity-building is needed, striving for integral optimisation – '*sector coupling*' – of the energy system, i.e. not just buildings, but the total system: buildings, transport, heat and power, industry, water and waste treatment and agriculture.

Much better monitoring and data is needed to steer the process. Digitisation should be made use of, e.g. reporting using the full Innovation in science pursuit for inspired research (INSPIRE)[2] framework, allowing better exchange of best practices. Quick wins should be picked first, and strictly implemented: a good example is the updated Article 8, EPBD, requiring the installation of self-regulating devices when heat generators are replaced. Member States should also try harder to monetise the system-wide benefits of NZEB building stock: we found, for example, that European NZEB building stock could save EUR 10 billion in avoided upgrades in the power system's transition to zero-GHG emission.

Is the concept of NZEB the best approach to achieving decarbonisation goals?

NZEB is an excellent approach – as long as it is interpreted as a concept focusing on the health and comfort of its users, mirroring a cost-effective, full decarbonisation of the energy system.

There is a risk of sub-optimisation caused by the EPBD's sole focus on operation and '*building services*'. I like the US approach of including standardised appliances and plug-loads in buildings' energy balances. When you have a PV system on your roof, it inevitably serves your heat pump and your TV; how and why would you split up the PV power to heat pump and TV?

We also need to think about minimising the total lifecycle footprint of buildings. Approaches like DG Environment's '*Level(s)*' framework[3], focusing on the environmental impact of building construction, are much needed. Like appliances and plug-loads, construction has a very significant share in the total footprint. This kind of thinking will help us achieve buildings with minimum lifecycle footprint.

ANDREAS HERMELINK

Dr. Andreas Hermelink is a Director with Navigant's energy practice. He holds university diplomas in Business Administration and Civil Engineering and a PhD in Sustainability Evaluation of Buildings. With almost 20 years of experience on various aspects of very low energy buildings – environmental lifecycle performance, certification, cost-benefit analyses, user behaviour, barriers for uptake, integration in district-wide solutions – Dr. Hermelink consults for major public and corporate clients. In 2007 he was awarded the European Solar prize and frequently supports conferences as speaker, session moderator and member of the scientific committee.

1 https://ipcc.ch/
2 http://online-inspire.gov.in/
3 https://ec.europa.eu/environment/eussd/buildings.htm

ARTICLE

EPBD19a FEASIBILITY STUDY ON BUILDING RENOVATION PASSPORT – DEFINITION AND FIRST RESULTS

Europe faces a momentous challenge to achieve a highly energy efficient building stock by 2050, with buildings currently the single largest energy consumer. According to data from the EU Building Stock Observatory[1], more than three quarters of our buildings were constructed before the Berlin Wall came down in 1989. The standard of new buildings has steadily improved since then, yet most existing buildings will still be in place in 2050. With around 1 % of building stock renovated each year and with most renovations only achieving modest energy savings, it is the clear that the number and depth of renovations must increase to make this vision a reality.

Deep renovation is a complex process that involves a complete overhaul of the energy performance of a building. Most people are aware that better insulation of walls, roofs and basement will lower the energy consumption of the household. However, many people are not aware of the issue of air leakages[2], allowing heat to escape the building through weak points in the building envelope. Achieving a successful deep renovation requires expertise and careful detailing of the renovation measures, especially when a deep renovation is achieved in several stages. The building renovation passport can facilitate this by providing a tailored renovation roadmap for a specific building, which can be carried out in one stage or in multiple steps over several years.

> *The building renovation passport provides a tailored renovation roadmap for a specific building, which can be carried out in one-stage or in multiple steps over several years*

Article 19a of the *energy performance of buildings Directive*[3] requires the European Commission to carry out a feasibility study[4] to identify the need, possibilities and timeline for introducing EU provisions related to a building renovation passport. The study[5] is ongoing, and the results will be published by the end of the year. The following definition has been developed by the Buildings Performance Institute Europe (BPIE) in this context, based on exchanges with experts and stakeholders: *'A building renovation passport provides a long-term, tailored renovation roadmap for a specific building, following a calculation based on available data and/or an on-site audit by an energy expert. The instrument identifies and outlines deep renovation scenario(s), including steps to implement energy saving measures that could improve the building's energy performance to a significant higher level over a defined period of time*[6]*. The instrument can be complementary to energy performance certificates and/or combined with digital logbooks.'*

The first part of the study comprised a comprehensive review of existing building renovation passports[7], which found that:

- The most successful schemes have combined renovation advice with financial support, legal obligations, and/or communication campaigns. The review concludes that building renovation passports need to be integrated with, and reinforced by, other elements in order to be effective.

- The instrument can be effective in alleviating two of the main barriers to renovation: low awareness of the benefits of energy renovation and insufficient knowledge of what measures to implement and in which order. The study shows that tailored renovation advice, together with other support measures, has a real impact on the decision to renovate, the number of measures to implement, the performance level of the selected measures and the type of measures implemented.

- Financial constraints are the main reason why building owners choose less efficient solutions, hampering the transition to an energy-efficient building stock. Targeted renovation advice is needed to better align the direction of private investments with the long-term vision for building stock.

- The existing schemes do not target any hard-to-reach groups (people not interested, low-income households, etc.) and rarely tackle indoor environmental quality.

> *Homeowners need advice and support throughout the whole renovation journey of their dwellings*

The building renovation passport is not the only answer to the need for awareness raising, renovation advice and assistance for homeowners. Homeowners need advice and support throughout the whole renovation journey. The building renovation passport is just one instrument that needs to be embedded in a broader energy-advisory-service framework and supported by other policies. The instrument can, however, contribute to a better alignment of short-term investments and long-term targets for the building sector. It represents an opportunity to create further synergies with other support instruments and helps to decrease technological lock-ins.

JONATHAN VOLT

Jonathan Volt is a political scientist and project manager at Buildings Performance Institute Europe in Berlin. Since he joined BPIE in 2016, he has worked on a number of projects aiming to reduce the climate impact of European building stock. He is currently exploring the concept of building renovation passports in the EPBD19a feasibility study and the Horizon 2020 project, iBRoad.

1 https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/eubuildings
2 Leakages often occur through junctions between walls and other walls and between walls and windows.
3 *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings*
4 The feasibility study is contracted to a consortium formed by INIVE and BPIE. BPIE is responsible for the part on building renovation passports, with the help of national experts including IFEU and the Shift Project.
5 https://epbd19a.eu/
6 The time of the roadmap could span from 5 to 20 years and the definition of the time horizon should be left to the implementing authority based on national/local conditions. The building owner can, of course, opt to implement all steps in one go.
7 Including similar initiatives also providing tailored renovation advice, including energy audit frameworks, advanced energy performance certificates, one-stop-shops and online renovation advice tools.

ARTICLE

Occupant behaviour and the energy savings gap in Hellenic residential buildings

Residential buildings in Greece account for 27.5 % of the country's total final energy use (Figure 1), and are responsible for 21.7 % of total carbon dioxide emissions[1]. Space heating (56.2 %) and domestic hot water (DHW) (13.5 %) are the most important end-uses[2]. According to the latest national Buildings Census, there are ~3 million exclusive residential use buildings, representing ~79 % of the building stock[3]. The grim reality is that the vast majority lack proper thermal protection and have ageing heating, ventilation and air conditioning (HVAC) installations, failing to meet the new energy efficiency standards according to the national transposition of the EPBD[4] mandates, KENAK[5].

A bottom-up building stock model has been developed for Hellenic residential buildings, based on the national TABULA typologies for assessing energy conservation measures and quantifying savings from renovation scenarios[6]. However, the gap between calculated and actual energy use has long been recognised as a major hurdle for realistic assessments of building performance[7].

> *Residential buildings in Greece account for 27.5 % of the country's total final energy use in 2017, and are responsible for 21.7% of the total carbon dioxide emissions*

To make more realistic estimates of actual energy use, heating energy consumption calculated by KENAK can be adapted using empirical factors derived from data included in energy performance certificates (EPC) or collected from simple behavioural occupant surveys.

Data from the Hellenic EPC repository[8] was used to derive empirical adaptation factors, defined as the ratio of the specific actual (operational) energy use to the normative calculated (asset) final energy consumption from each building. Figure 2 illustrates the final energy use intensities (EUIs) for space heating and DHW derived from 1899 EPCs issued in 2011-2018. The large variations can be attributed in part to unique building characteristics, prevailing weather conditions, occupant behaviour and the deviation of actual operating conditions from the default values used in calculations.

1 *Energy statistical country datasheets*, European Commission, DG Energy, Unit A4, July 2019.
2 *Energy consumption in households*, Eurostat, May 2019.
3 *Buildings Census 2011*, Hellenic Statistical Authority (ELSTAT), Athens, 2015.
4 *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings*
5 Dascalaki E.G., Balaras C.A., Gaglia A.G., Droutsa K.G., Kontoyiannidis S., *Energy Performance of Buildings - EPBD in Greece*, Energy Policy, Vol. 45, 2012, pp. 469–477.
6 Dascalaki E.G., Balaras C.A., Kontoyiannidis S., Droutsa K.G., *Modeling Energy Refurbishment Scenarios for the Hellenic Residential Building Stock Towards the 2020 & 2030 Targets*, Energy & Buildings, Vol. 132, 2016, pp. 74-90.
7 Balaras C.A., Dascalaki E.G., Droutsa K.G., Kontoyiannidis S., *Empirical Assessment of Calculated and Actual Heating Energy Use in Hellenic Residential Buildings*, Applied Energy, Vol. 164, 2016, pp. 115-132.

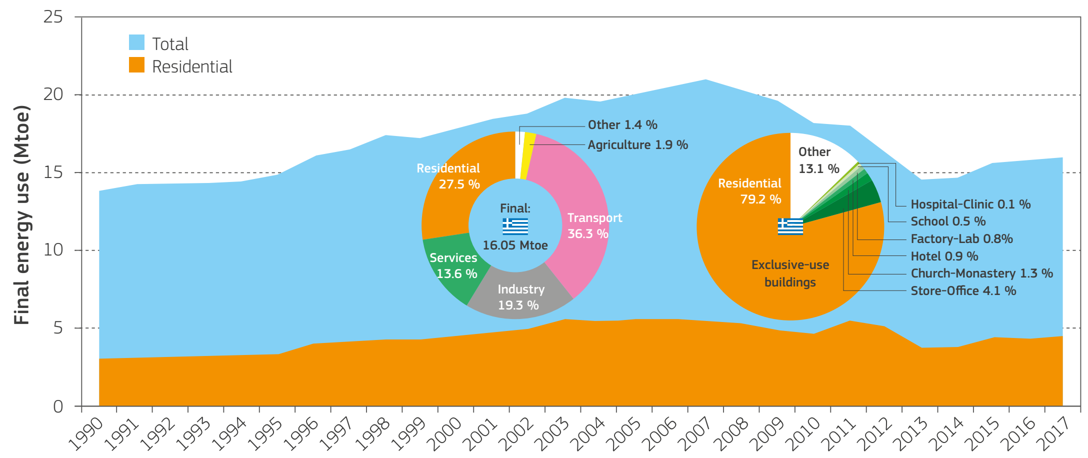


Figure 1 - Evolution of total final energy consumption in Greece. The doughnut chart summarises the final energy consumption by sector and the pie chart illustrates the breakdown of exclusive-use buildings in Greece. Source: EUROSTAT and ELSTAT.

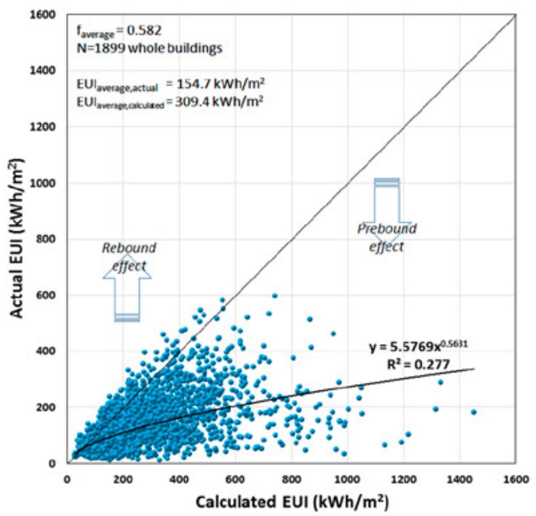


Figure 2 - Scatter plots and power regression curve of data for the calculated and actual space heating & DHW final EUI (kWh/m2) from 1899 residential buildings in Greece. The 45-degree line (x = y) represents scenarios where the calculated and actual energy consumption values match. Source: Buildingcert.

> *Moving forward, the big challenge is to improve the energy performance of our buildings while securing proper indoor environmental quality*

The average adaptation factor is 0.584 (i.e. 41.6 % lower actual energy use than calculated). In general, higher calculated EUIs correspond to lower actual energy use, known as the 'prebound' effect. This is more evident for dwellings with a high calculated EUI (i.e. poor energy performance). This corresponds with published results of actual energy use ranging from 30 % to 47 % less than calculated space heating[9].

COSTAS BALARAS

Costas Balaras is a mechanical engineer and holds a PhD from Georgia Tech. He is a research director at the Institute for Environmental Research & Sustainable Development (IERSD) at NOA in Athens, Greece. He is active in energy conservation, high performing buildings, sustainable cities, thermal and solar applications, building energy audits diagnosis and environmental impact assessments. He has participated in around 50 R&D and demonstration projects and was instrumental in the national adaptation of EPBD in Greece. He has published over 250 articles in journals, books and conference proceedings. He is a chartered engineer in Greece, an ASME Fellow and ASHRAE Fellow.

8 *Buildingcert - National EPC repository*, Hellenic Ministry of Environment & Energy in collaboration with CRES.
9 Galvin R., Sunikka-Blank M., *Quantification of (p)rebound effects in retrofit policies – Why does it matter?*, Energy, Vol. 95, 2016, pp. 415-424: https://doi.org/10.1016/j.energy.2015.12.034

> *On the more important end of indoor comfort conditions, only half of the occupants manage to feel comfortable in their dwellings*

The opposite phenomenon is known as the 'rebound' effect, when actual energy use is higher than calculated, most notable in low-EUI dwellings (i.e. good energy performance). The values reported range from 36 % to 51 %.

Periodically updated field surveys of homeowners in 278 dwellings reveal additional insights into behavioural changes and trends in the use of heating systems (Figure 3).

According to field data, only about 14.3 % of single-family houses (SFHs) and 9.3 % of multi-family houses (MFHs) have operating hours close to the assumed continuous heating (Fig. 3a). Distribution peaks around 3-4 and 5-6 hours per day in SFHs and MFHs respectively. About 69 % of SFHs and 78 % of MFHs operate their central heating for less than eight hours. Isolating some rooms is another common practice by homeowners for reducing energy costs (Fig. 3b). Only 38 % of SFHs and 44 % of MFHs heat their entire dwelling. A notable trend revealing the impact of the recent recession in Greece and of high heating

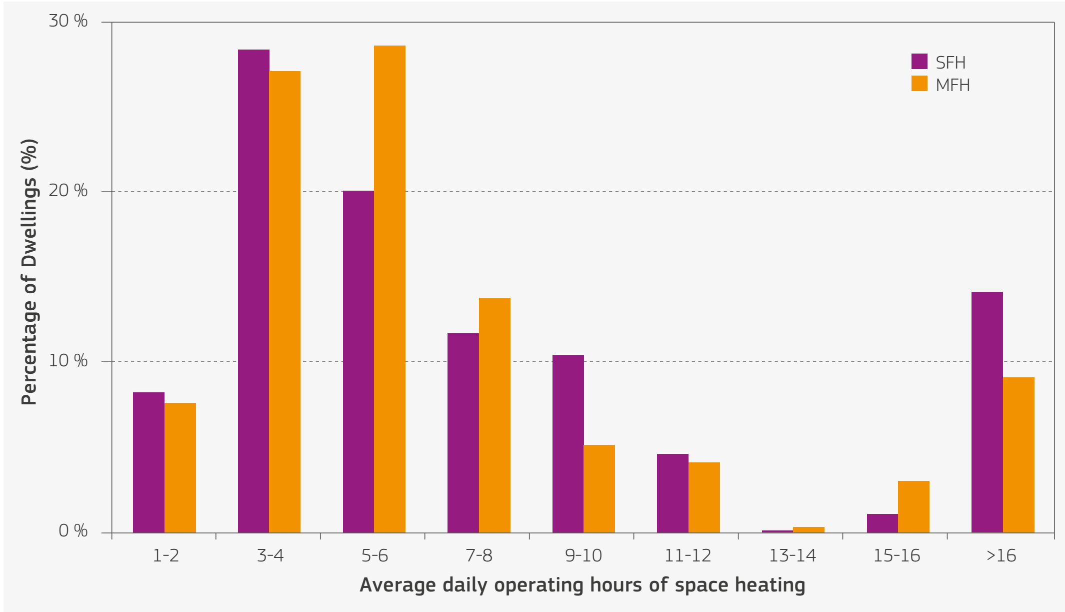


Figure 3a

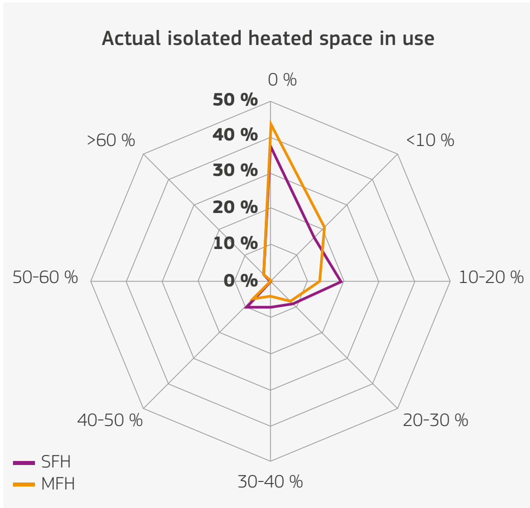


Figure 3b

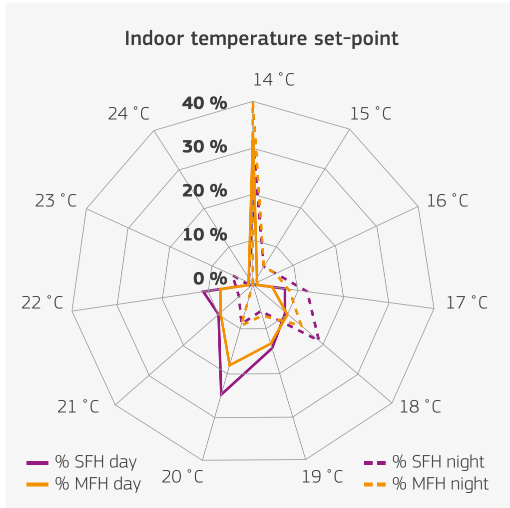


Figure 3c

Figure 3 - Actual operating characteristics in single-family (SFH) and multi-family (MFH) houses from field surveys. (a) Average daily operating periods of space heating systems; (b) Percentage of isolated non-heated floor areas; (c) Percentage of average indoor day and night set-point temperatures. The grey shaded areas identify the assumed values used in the normative calculations. Source: Own datasets.

oil prices (through taxes) is that 26 % of MFHs have turned off their central heating systems, and over 16 % of SFHs. Lowering the temperature is another common way to reduce heating costs, even at the expense of thermal comfort. Only 25 % of the occupants of SFHs and 19 % in MFHs reported an average temperature setting of 20 oC (Fig. 3c), the indoor set-point used in normative calculations. The derived adaptation factors that address these deviations are 0.40 for heating operating hours, 0.89 for reduced heated floor areas and 0.86 for indoor temperature. These factors can be used as multipliers to obtain more realistic estimates of actual energy use. The unfortunate impact of these behavioural trends is that only half of occupants (52 % of SFHs and 45 % of MFHs) feel comfortable in their dwellings, while 6 % of SFHs and 10 % of MFHs are forced to live in severely adverse conditions.

ELENA DASCALAKI

Elena Dascalaki is a building physicist and holds a PhD from the University of Athens. She is a senior researcher at the Institute for Environmental Research & Sustainable Development (IERSD) at NOA in Athens, Greece. She currently works on building typologies and building stock modelling, lifecycle analysis, building thermal simulations, and computational fluid dynamics. She has participated in over 35 R&D and demonstration projects and published over 130 articles in journals, books and conference proceedings.

ARTICLE

Epilogue: Implementation of the SET Plan Action on energy efficiency solutions for buildings

The Implementation plan on energy efficiency solutions for buildings (SET Plan Activity 5) was endorsed by the SET Plan Steering Group in November 2018. The implementation working group (IWG) 5 consists of two sub-groups focusing on '*New materials and technologies for energy efficiency solutions in buildings*' and '*Cross-cutting heating and cooling technologies for buildings*' and covers a large number of topics.

A promising kick-off meeting was held in June 2019. In total, 18 Members, including national representatives, stakeholders and representatives of the European Commission, came together in Brussels to discuss ways forward, including funding options for joint actions as well as suitable means to measure the progress of executing the Implementation plan. A catalogue of key performance indicators (KPIs) was finalised, addressing the various targets, such as increasing the amount of renewable heat in district heating and cooling by 25 %, and cutting down on renovation time and cost for energy-related retrofits.

As different challenges require different approaches, the IWG not only focuses on new developments but also looks at synergies and efficient ways to disseminate existing solutions. Stakeholders from the shallow geothermal and the heat pump community are actively cooperating with IWG 5 regarding decarbonised heating and cooling solutions. To reach the 2050 climate goals, all heaters using fossil fuel should be replaced by carbon-neutral systems by 2030. While shallow geothermal energy is considered a niche technology, it has the potential to be a game changer for the transition to clean energy for all Europeans.

> *Buildings cannot be considered as stand-alone quantities, though, as they are connected to the energy grid on one hand and form a district as part of a city on the other*

Buildings cannot be considered as standalone quantities though, as they are connected to the energy grid on one hand and form a district as part of a city on the other. An overlap exists with other IWGs, such as IWG 4, considering the resilience and security of the energy system, and IWG 3.2, on positive energy districts. There is exchange among these working groups, and possibilities for joint actions will be assessed.

The SMARTSPEND programme recently delivered an overview of overlapping activities among the various SET Plan Implementation plans that will serve as guidance for the establishment of joint actions. An example that I would like to highlight are living labs, combining energy-efficient buildings with their surroundings, including the district and the people living there, who must be involved to enable the energy transition. A wider perspective should also be taken when considering the lifecycle of buildings and their components.

> *Together with new developments, synergies and efficient ways to disseminate already existing solutions are the focus of the SET Plan Implementation Working Group on buildings*

Cooperation with the European Energy Research Alliance (EERA) is also planned. As there is currently no EERA joint programming tailored to the targets of SET Plan Activity 5, alternative options, such as suitable sub-programmes, are under consideration.

The next physical meeting of IWG 5 is to take place in Helsinki in November 2019, during the SET Plan conference. Anybody interested in contributing to the IWG is welcome to join.

JENNIFER REICHERT

Jennifer Reichert is part of the scientific staff at Project Management Jülich, a national funding agency in Germany. In the Department of Energy Efficiency in Buildings she manages research projects on behalf of the Federal Ministry for Economic Affairs and Energy. As chair of Implementation Working Group 5, she has coordinated the execution of the Implementation plan since March 2019. Jennifer Reichert studied Metallurgy and Materials Science at RWTH Aachen University, Germany, and holds a PhD in Materials Engineering from the University of British Columbia, Canada. She has worked in the field of materials science in Brazil and Belgium.

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SETIS Magazine

SETIS launches a new magazine quarterly, each issue is dedicated to a different low-carbon energy technology or relevant aspects of the sector. It covers the latest developments in the subject in question. Relevant personalities are invited to write articles outlining the main challenges and priorities facing their sectors, and interviews are conducted with key representatives from the related topic.

The magazines also include a SET Plan news section detailing the last developments to achieve the Integrated SET Plan objectives, and European Commission services and/or relevant organizations/institutions are invited to provide a foreword that highlights the main policy developments on the subject.

Energy efficiency in buildings

This edition of SETIS Magazine takes a closer look at the current status of the EU building stock and its future evolution. It discusses the energy transformation of Europe's buildings, along with the challenges and policy actions ahead. We bring together experts from the research and policy communities to discuss the most relevant and pressing issues on energy efficiency in buildings today. Their input sheds light on the question: What is the potential contribution of buildings in the transition to climate neutrality in 2050?

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