Proceedings of the International Conference
‘Smart Energy Regions’
Cardiff, UK, 11th and 12th February 2016

Edited by Jo Patterson and Fabrizio Varriale
This publication includes work from the COST Action TU1104 Smart Energy Regions, supported by COST (European Cooperation in Science and Technology).

COST is supported by the EU Framework Programme Horizon 2020.

© COST Association, 2016

No permission to reproduce or utilize the contents of this book by any means is necessary, other than in the cases of images, diagrams or other materials from other copyright holders. In such cases, permission of the copyright holders is required.

This publication may be cited as: Proceedings of the International Conference ‘Smart Energy Regions’, Cardiff, UK, 11th and 12th February 2016

Published by:
The Welsh School of Architecture, Cardiff University,
Bute building, King Edward VII Avenue, Cardiff, CF10 3NB, Wales UK

Publication date: March 2016
ISBN: 978-1-899895-23-6
Contents

Introduction .................................................................................................................................................. 5
COST - European Cooperation in Science and Technology ................................................................. 6
Manifesto for a zero carbon future built environment .............................................................................. 7

Presented papers ....................................................................................................................................... 11
Session 1: Energy policy, strategy, cost and value ............................................................................... 12
Regional governance and low-carbon investments in the built environment in Slovenia .................. 13
From smart cities to smart regions – a field report .............................................................................. 22
Energy efficiency programmes in the spotlight - Analysis of governmental, institutional and entrepreneurial energy efficiency programmes: target groups, governance mechanisms and factors of success .................................................................................................................. 31
Influence of incentives, occupancy and energy-related behaviours on renovation strategies decision making ........................................................................................................... 45

Session 2: Urban planning and infrastructure ..................................................................................... 58
Welsh and Romanian policies for transition towards low carbon mobility ....................................... 59
Success factors and barriers for 100% renewable energy-regions ...................................................... 70
Energy modelling of regions using stakeholder generated visions as scenarios .................................. 84

Session 3: Energy retrofitting of the built environment ....................................................................... 97
The impact of UK Government policy instruments on quality in domestic solid wall insulation retrofit projects ........................................................................................................................ 98
Planning of cost-effective and energy-efficient retrofitting actions: a comprehensive energy audit approach .................................................................................................................................... 109
Improving the district heating system in Belgrade - towards smart energy consumption ................. 121
Evaluation of a regional scale retrofit programme to upgrade existing housing stock to reduce fuel poverty, reduce carbon emissions and support the supply chain .............................................. 132
Low energy renovation of neighborhoods in southern Europe – a realistic challenge or an unviable goal? ........................................................................................................................................ 143

Session 4: Building energy demand and supply, and low carbon technologies .................................. 165
Synergistic benefits of renewable energy sources and electric vehicles in autonomous grids ......... 166
Exploring the impact of product substitution in the supply of domestic thermal insulation in Wales ........................................................................................................................................ 176
From energy behaviours to energy resources optimisation in smart(er) grids: development of an energy management system ................................. 201
Session 5: Energy design tools, modelling and data management for the built environment

Natural ventilation in retrofit and new dwellings: a pan-European assessment

Performance-based clustering for building stock management at regional level

The role of analytical tools in supporting sustainable local and regional energy and climate policies

Bottom-up modelling of continuous renovation and energy balance of existing building stock: case study Kočevje

Presented posters

Establishing a method to perform a BPS - Building Performance Simulation

Assessment of energy-related refurbishment strategies via Bayesian-Network Modelling

Design considerations for the integration of battery storage systems in UK communities

Development of a high resolution atmospheric urban scale model for energy applications in the built environment

SOLCER house – low carbon, low energy, low cost

PHCCPLUS Passivhaus (NZEB) Craftmens Course

Review and results of Early Stage Researchers Training School

Developing an optimisation tool for solar thermal system dimensioning in Lithuania

Energy efficient Campus – HoEff-CIM (Campus Information Modeling)

Application of phase change materials in building technologies

Some aspects of the smart region concept

The use of solar cadastre as an energy-planning tool at regional scale: estimation of PV potential, demand coverage and effects on the electricity grid infrastructure

Rapid building assessment using statistical techniques and powerful IT infrastructure

Energy efficient measures for existing and new buildings in Macedonia

Challenges of buildings modernization - Assessing the social and economic aspects: experience of Lithuania

Scenarios for - and a roadmap towards - the Smart Energy Region Zurich 2050
Introduction

The COST Action TU1104 ‘Smart Energy Regions’ started in March 2012 and ended in March 2016. During its four years of activity, the Action established a network of more than 70 researchers from 27 European countries and Israel, allowing the exchange of experience and engagement with local policy-makers and stakeholders.

The Action organised a Training School on energy retrofit for fifteen early-stage researchers, and enabled twenty-two researchers to conduct Short Term Scientific Missions in partner institutions. The main outputs of the Action are three publications collecting contributions from Action members on the topics of low carbon policy, technology, skills, training, supply chains, and cost and value. These and the other outputs of the Action can be found on the Action website: www.smart-er.eu

The international conference ‘Smart Energy Regions’ took place in Cardiff, UK, on 11th and 12th February 2016. The event gathered Action participants, international keynote speakers and invited delegates. This publication collects the papers and posters presented at the conference. Papers were presented orally according to the following thematic sessions:

1. Energy policy, strategy, cost and value;
2. Urban planning and infrastructure;
3. Energy retrofitting of the built environment;
4. Building energy demand and supply, and low carbon technologies;
5. Energy design tools, modelling and data management for the built environment.

The papers and posters presented at the conference are collected in this publication. The papers were selected and reviewed by the following members of the conference Scientific Committee:

Ingrid Kaltenegger  
JOANNEUM Research, Austria

Werner Lang  
Technische Universität München, Germany

P. Amparo López-Jiménez  
Universitat Politècnica de Valencia, Spain

Jo Patterson  
Cardiff University, United Kingdom

Jaime Roset-Calzada  
Universitat Politècnica de Catalunya, Spain

Derek Sinnott  
Waterford Institute of Technology, Ireland

Fabrizio Varriale  
Cardiff University, United Kingdom

If you require a higher quality PDF of a particular section of these proceedings, please email smarter@cardiff.ac.uk
COST - European Cooperation in Science and Technology

COST (European Cooperation in Science and Technology) is a pan-European intergovernmental framework. Its mission is to enable break-through scientific and technological developments leading to new concepts and products and thereby contribute to strengthening Europe’s research and innovation capacities. It allows researchers, engineers and scholars to jointly develop their own ideas and take new initiatives across all fields of science and technology, while promoting multi- and interdisciplinary approaches. COST aims at fostering a better integration of less research intensive countries to the knowledge hubs of the European Research Area. The COST Association, an International not-for-profit Association under Belgian Law, integrates all management, governing and administrative functions necessary for the operation of the framework. The COST Association has currently 36 Member Countries.

www.cost.eu
Smart Energy Regions:
Manifesto for a zero carbon future built environment

Our generation has the singular chance and opportunity to keep the world’s climate stable. The COP21 has committed countries to a zero carbon future. The COST Action TU1104, Smart Energy Regions (Smart-ER) is concerned with the transition of this international agreement to a low carbon built environment, and identifying ways to achieve this within a time scale that can meet policy-related carbon emission reduction targets.

Smart-ER’s 28 member countries have reviewed the drivers and barriers that may impact on the long-term creation of zero carbon regions in Europe. The term ‘smart’ applies to energy supply and energy demand, from smart grids to smart living, with an emphasis on a ‘bottom-up’ people based approach, and not necessarily ICT-based. Greenhouse gas emissions from energy consumption are looked at from a built environment ‘systems’ approach, linking reduced energy demand, renewable supply and storage. This has all been considered at a regional scale, relating government policy and aspirations, to industry capacity and needs, whilst encouraging people and organisations to be as resource efficient as possible. The Action has identified case studies relating to the drivers and barriers associated with smart energy regions, illustrating good and best practice. The focus has been on innovative technologies and processes associated with resource efficiency and demand reduction, with reference to cost and value, skills and training, and supply chains, and the current trend towards a circular economy. This Manifesto presents a set of actions that are essential in order to speed up the transition to a zero carbon society.

Speed up the transition of zero carbon design and technology into practice in the built environment. The evidence relating to global warming, polluted air and security of supply is overwhelming. There is no excuse to wait. Technology is available. Every project should strive to be zero carbon.

There are impacts from burning fossil fuel at global, local and building scale, in relation to climate change, air pollution, and security and affordability of energy supply. The need for a transition to a zero carbon built environment is an essential part of the future zero carbon economy, which will be based on energy efficiency, and 100% use of renewable and clean energy supply. The problem is how, and over what period, this transition takes place, how government and industry will rise to the challenge, and how research can inform the process. Currently it is becoming apparent that things are taking too long and the transition of zero carbon goals from policy through to practice needs to speed up dramatically. Zero carbon targets, both medium and long term, are strategically needed, but there is a danger that they introduce complacency and ‘carbon fatigue’, and place the emphasis on decision-making into the future. Real action is needed now, and from now on, every built environment project should strive to be zero carbon.
Challenge the status quo to remove the obstacles that inhibit the transition to a zero carbon built environment, and redesign our procurement methods such that they can help push forward the zero carbon agenda and facilitate the changes needed.

Depending on location, the built environment can account for around 40 to 50% of carbon emissions, more if urban transportation is included. For some 40 years, since the 1970’s oil crisis, our understanding has developed considerably, on how to design and construct a more energy efficient built environment, and technologies to generate renewable energy have significantly moved forward, and yet available and viable low carbon technologies are still not widely applied in practice, nor fully appreciated by policy makers. Often, current procurement practices and vested interests are protected by standards, regulations, framework agreements, and hidden subsidies. We are locked into current practices, resulting in barriers to innovation and change. The delays in progressing towards a zero carbon built environment are therefore more related to the culture and processes of the construction industry rather than to a lack of technology.

All sectors of the construction industry need to engage with zero carbon goals. Government needs to differentiate between industries that support positive change with regards to environmental issues and those that do not. Government needs to provide greater support to those who want change, rather than propping up those that do not want change.

The low carbon industry is a major future growth area and will contribute to a vibrant clean future economy, with products that benefit both people and the environment. However, some industries seem to want to control change to their financial benefit, leading to a ‘disconnect’ between environmental policy and economic growth, and between business interests and ethical values. Although this will vary from county to country, industries that resist change generally have greater lobbying powers with Governments. They often receive subsidies and preferential taxation. On the other hand, some industries welcome change as a means to produce new innovative high value products that support the transition to zero carbon. These industries need to greater support from Government, including a fairer distribution of subsidies and tax incentives.

The culture of the construction industry needs to change and, where necessary, governments should attract and support new innovative industries into the market, driven from ‘bottom-up’ solutions, and identify exemplar projects that can be easily replicated, highlighting their local benefits in terms of jobs and wealth creation.

Most initiatives to reduce greenhouse gas emissions are central, top-down, and supply-driven, through existing industries, which may resist change, which in some counties might include the energy supply industries and mass house builders. Some governments seem to prefer big industry solutions for achieving reductions in greenhouse gas emissions. However, to date, the focus on top-down solutions to reduce emissions has failed to deliver a viable sustainable future energy scenario. Many top-down solutions are not sufficiently developed, such as large-scale energy storage, carbon capture and storage, smart grids, and carbon credits. These will take huge investment, and by the time they are developed they may as well be obsolete. Bottom-up solutions are more demand-driven, dealing with specific projects, often at community scale level. The old energy-related industries have a culture and interests that seemingly cannot adapt to the changes that are needed quickly enough. New
industries and new business models that focus on bottom-up activities may more readily bring about change, whilst also supporting local economies through jobs and wealth creation.

Rebalance top-down and bottom-up approaches to maximize the impact and speed of transition of zero carbon technologies, with an emphasis on creating and increasing bottom-up demand-led activities, leading to tangible added value multiple benefits.

The potential way forward may be to focus more on a bottom-up ‘systems’ approach, applying existing solutions, linking reduced energy demand, renewable energy supply and energy storage, at a building and community scale. Smart-ER has identified a range of technology ready solutions that, with the appropriate training and skills development, can produce affordable and replicable solutions. The implementation of low energy technologies often comes with added value ‘multiple benefits’, such as improved quality of life, reduced fuel poverty, improved health, and local economic spin-offs. These benefits will be regionally driven, providing stakeholder action, jobs, investment and profits, all at a local scale. This approach relates more to people’s day-to-day decision-making, compared to the more abstract concept of reducing greenhouse gas emissions, which people may not fully understand, or be able to relate to their daily actions. We will still need central top-down solutions and strategic thinking, for large-scale renewables, smart grids and clean energy, but these will need to be combined with bottom-up solutions in a complementary, and not an opposing way.

Activate ‘middle-out agents’ that are able to effect change, who can make informed decisions, and who are properly equipped to implement systematic change, through best practice and operational excellence, and through a cycle of continuous improvement.

An opportunity to rebalance these bottom-up and top-down approaches, and enhance community ownership, may lie in recognizing the potential attributes of a ‘middle-out’ approach. Middle-out ‘actors’, such as community and professional organizations can be the agents of change. They can provide a link between top-down and bottom-up, having capabilities, the structure and power, to negotiate with top-down decision makers, and can offer leadership and empowerment to bottom-up initiatives. The people involved will usually have a personal/professional (and maybe vested) interest in effecting this change at a community/regional level, and have the knowledge and skills to mediate, develop supply chains, and add value to existing tools and techniques by adopting lean and integrated approaches.

Use the knowledge triangle of Government, Industry and Research to spin out innovative solutions, to provide a more effective transition of zero carbon policy into practice, across the built environment. There should be clear transition routes and government forward planning from policy to practice, to which industry and the public can respond.

There is currently a ‘disconnection’ between elements of the ‘knowledge triangle’ comprising government, industry and research, and their links to society. Communication is often weak, both within the sectors, for example, between different government departments, and across the sectors, for example between government and industry. Government policy sometimes changes too slowly, for example, in response to climate change. Sometime changes are not fast enough, or they are
erratic, in relation to industry time-scales for developing new products, and the skills required to apply them effectively. We need to recognize the tensions within the knowledge triangle, with industry split between those supporting, and those not supporting change, that government has both top-down and bottom-up interests, and that research may be perceived as too theoretical with poor dissemination into practice. Government decisions must be unbiased and research-based evidenced, with clear transition paths identified to enable industry to forward plan, and develop new skills, finance models and stable supply chains.

The research sector must provide a greater knowledge and understanding to government policy-makers, industry and the public at large on visioning a future zero carbon built environment, in a language that all can relate to, in their everyday decision-making situations, and ultimately everyday life, and highlighting the role of all people. We need to create a bottom-up demand for zero carbon solutions.

There are good examples of the application of zero carbon technologies at a regional scale, such as those illustrated through the Smart-ER case studies. However, the rate of replication of exemplar demonstration projects into standard practice is too slow. Reasons may include, the lack of understanding of what is possible and the fear of taking a risk, at both policy level, and from an end-user perspective. The research sector has a crucial role in dissemination and demonstration of zero carbon solutions, to tangibly influence decision makers in both government and industry. There is evidence that when this understanding is demonstrated effectively to both government policy-makers and end-users, there is a high level of interest, which stimulates a demand for change. Top-down international policy agreements, such as the COP21, are essential, but not enough on their own. A zero carbon built environment will only be achieved in the short timescale left, through a wide-scale bottom-up demand from organisations, communities and the public. The challenge now is to create this demand!

This Manifesto is the result of the collaborative efforts of all members of the COST Action TU1104. Stand-alone PDF versions of this Manifesto in English and several other European languages can be downloaded from the Smart Energy Regions website: www.smart-er.eu
Presented papers
Session 1: Energy policy, strategy, cost and value
Regional governance and low-carbon investments in the built environment in Slovenia

Tina Schmieder-Gaite

Welsh School of Architecture, Cardiff University, Bute Building, King Edward VII Avenue, CF10 3NB Cardiff, E-Mail: schmiedert@cardiff.ac.uk

Abstract: The EU’s commitment to reducing its carbon emissions by 80% by 2050 has led to an array of climate change and energy umbrella policies. With currently 28 diverse member states, these policies are transposed to the national and regional level with varying degrees of efficiency, speed and proactivity. A number of directives and laws within this overarching policy landscape have been developed with a particular view to increase the energy efficiency of the built environment.

This paper explores the financial and governance dimensions of decarbonising the European built environment through the example of the Podravje region in Slovenia, drawing on recent fieldwork interviews, local documents and other secondary sources. It investigates the funding of energy efficiency in the built environment, under the hypothesis that decentralised governance levels may be important for the effective local transposition of EU energy efficiency legislation. It is found that structural differences particularly at the regional and local governance levels in Slovenia have a direct and significant impact on low-carbon investments at the local or municipality level. The absence of an effective regional administrative level may prove to be an impediment to Slovenia achieving EU sustainability targets.

The main barriers to the decarbonisation of the Slovenian built environment are identified as relating to issues of governance, funding and information, with governance the most far-reaching. It is suggested that developing strategies to strengthen the regional governance level would facilitate the country’s transition to a more sustainable built environment, and as such support the EU’s carbon reduction targets.

Keywords: energy efficiency, regional governance, energy policy, low carbon investments, Slovenia

Introduction

Research increasingly points towards a trinity of imperative factors for a shift towards an energy efficient built environment – governance, funding and information (Bolton & Foxon 2015; EEFIG 2014, Colenbrander et al 2015). While the need for more awareness and detailed and appropriate information on energy efficiency has been covered elsewhere (Lützkendorf et al. 2011, Häkkinen and Belloni 2011) research on effective interaction between governance levels and funding is an emerging area that is drawing increasing interest (Buchner et al. 2014, Rozenberg et al. 2012). While attention is rightly often drawn to the supranational and national governance levels for their importance to the setting and achievement of overarching sustainability targets, this paper focuses on the regional governance level as their connector to the local level.

Slovenia, one of the smallest member states in the EU, with a population of only 2 million, shows a disconnection between its governance levels. Since its independence from Yugoslavia in 1991, Slovenia’s governance structure has been described as “highly centralized, with no pre-existing regional administrative level” (Lindstrom 2005, p. 1). Instead, the country is divided in 211 municipalities which act as “basic administrative units of local autonomy”. This municipality-focused approach has led to a “tradition of regionalism and local self-government” (Sitar and Krmelj 2014, p. 241).
Between 2007 and 2013, Slovenia’s debt more than tripled to 70% of its GDP (StatSlovenia 2014). An economically well-developed country with approximately 75% of its inhabitants living in urban areas (Lindstrom 2005), Slovenia is per capita the richest nation of the Slavic countries. Though many of the other EU member states are now on the path to recovery from the financial crisis of 2008, Slovenia is still struggling, both economically with a lack of investments and budget cuts in the public sector, a high rate of bankruptcy in the private sector and high unemployment figures. As a result, it has been suggested that the population is reacting with conservative consumer decisions and a general feeling of apathy and passiveness, leading to few low-carbon investments across the country.

The Municipality of Maribor has been chosen as a case study for this paper. It is the second-biggest city in Slovenia with approx. 115,000 inhabitants behind the capital Ljubljana and lies north-east in the statistical region Podravje along the river Drava at the foot of the southern-most Alps. With a long heating period averaging 227 days annually, energy consumption is a high concern to the municipality (Sitar and Krmelj 2014, p. 242). Most buildings in the municipality are domestic buildings, meaning that the residential sector takes up the highest share of 40% of the municipality’s energy consumption, in comparison to 24% on average in the rest of the EU.

Methodology

A COST Action Short-term Scientific Mission award allowed the opportunity to investigate various perceptions about the interaction between legislation, funding and energy efficiency activities in the Podravje region. As the data collection was undertaken in 2014, the qualitative data reflects the country’s economic struggles as it emerged from the economic crisis. The support of a host organisation facilitated a number of meetings with Slovenian experts on governance, energy efficiency and sustainability.

The research is based on semi-structured interviews with 14 energy experts, academics, civil servants and senior public sector managers, following a predefined starting list of open-ended questions on energy efficiency, retrofitting, legislation and governance, as well as funding and investment. The interviews were transcribed and the qualitative data coded following Foxon’s five co-evolutionary dimensions of environment, institutions, technology, business and society (Foxon 2011). The coding allowed for an emergence of possible patterns across the co-evolutionary dimensions in the coding nodes. Primary data from the interviews were then combined with findings from a literature review of academic as well as grey literature and government reports.

While this paper focuses on Maribor and the Podravje region, it is part of a comparative study between three regions in the United Kingdom, Slovenia and Germany which is funded by the UK Engineering and Physical Science Council.

Maribor and the Podravje region

With low-carbon energy readily available in the municipality from nuclear, thermal and hydro sources (IEA 2012), Maribor has invested in embedding sustainability and energy efficiency into its governance. In 2001, it became the first municipality in independent Slovenia to adopt a modern spatial planning document, called the Urban Development Concept for the City Municipality of Maribor. Soon after, it committed to two additional sustainability-focused strategies, the Local Agenda 21 and the Environmental Action Programme 2004-2008, which covered energy savings and carbon emissions targets. Several Slovenian municipalities moved to establish energy agencies as “formal and semi-formal entities responsible for, among others, the promotion of energy efficient measures, and for providing information on possible financial support from various EU incentives addressed to individuals and other segments of the private and public sectors” (Cirman et al. 2012, p. 198). In 2006, the Energy Agency of Podravje (EnergaP) was established to serve the population of approx. 180,000 in Maribor and the surrounding municipalities. The agency played a crucial role for the municipality in adopting its Local Energy Concept, which contains a number of long-term sustainability objectives. It
has also been pivotal in reporting on and achieving its energy-efficiency targets since its establishment (Sitar and Krmelj 2014).

Slovenia, like many other European countries, has an old building stock which holds a big as yet unexploited potential for energy efficiency improvements and carbon reduction. In 2013, there were 857,000 dwellings in Slovenia, most of which were built between 1961-1970 (14%), 1971-1980 (21%) and 1981-1990 (17%) (StatSlovenia 2014). Cirman et al. (2012) found that over 70% of Slovenian domestic buildings are older than 30 years and the large majority (71%) of these have never been retrofitted. Sitar et al. (2009) found a significant change in the Slovenian domestic building stock between 1991 and 2002 with the proportion of privately-owned buildings growing from 67% to 92% (2009). 78% of the occupied buildings were owner-occupied (StatSlovenia 2013). A large proportion of the energy efficiency potential of the country’s built environment, and the responsibility to invest in it, lies with private home-owners, who for a number of reasons tend to struggle most to secure capital for these purposes.

The theme of finance as a barrier to energy efficiency has been emphasised in various forms in European publications (Stiess and Dunkelberg 2013, Leicester and Stoye 2013, BPIE 2011, BPIE 2012, Gouldson et al. 2012, Kumbaroglu and Madlener 2012, Curtin and Maguire 2011, etc.). In Slovenia, the financial barrier is most evident in “the difficulty to cover upfront costs” and the resulting lack of investment in general (Nieboer et al 2011, p. 11).

**The lack of regional governance in all but statistics**

While most other EU member states tend to have three practical levels of governance at the national, regional and local level, Slovenia has just two: the government, at the national level and the municipalities, at the local level. Its socialist history lies behind the absence of the intermediate governance level between municipalities and state, which would normally supervise the proper translation of supranational and national policies and programmes to the local and end-user level. Instead, Slovenia is structured into a number of statistical regions, which are a remnant of the former Yugoslavian regime.

“Regional planning in the 60s in Old-Yugoslavia, of which we used to be part, was confirmed on the basis of the republics and Slovenia as a republic back then had its own regional governance. That was very important. In the general planning which applied to all socialist states, the 5-year planning, the base was actually of an economic nature.”

In 1971, the law on the Promotion of Balanced Regional Development created special measures to promote the growth of less-developed sub-national regions without handing over any administrative power to the regions (Lindstrom 2005, p. 4). The function of Slovenia’s regions at that time was predominantly of an economic nature; this changed in 1991. Slovenia has since its independence “seen a high degree of centralization in resources and decision-making at the national level” and it has been suggested that it effectively made a step backwards by reducing the function of the regional level to be purely statistical (Lindstrom 2005, p. 4). This lack of political regional authority lasted throughout the 1990s, but eventually became a problem during Slovenia’s accession into the European Union.

“This regional level does not formally exist in reality. There is only the state and the municipality. And that is a big problem since the funding for various structural and cohesion funds etc. are allocated based on regional programmes and the harmonisation of the national and the local level. That is why a compromise has been developed in Slovenia. [...] This was a must; Slovenia had to have the regional programmes to even gain access to this financial environment.”

As becomes evident in the above quote, the EU programmes and policies rely on national and regional governance levels within the individual member states for their effective distribution and implementation, and aim to promote decentralised governance. Despite that, the EU exerts little or no control over the regional level.
“Regional planning is essentially not within the competency of the EU. Because that is the state, the national level.”

But as Lindstrom explains, “the Slovenian constitution made no provision for politically institutionalized regional bodies. Yet it did allow for voluntary cooperation among municipalities to unite as regions” (Lindstrom 2005, p. 6). So with the EU having no jurisdiction and the government preferring a centralised governance structure, it was left to the municipalities of Slovenia to organise themselves into regions. The municipalities, however, frequently consider each other competitors and “were more concerned with gaining competencies and resources than promoting development on the regional level” (Lindstrom 2005, p. 6).

Slovenian municipalities democratically elect their mayor and municipal councils. Once elected, however, it is often perceived that mayors have universal decision-making power for the entire community and therefore represent the highest authority at the local level.

“By the law the mayors have too much power. They are the most powerful person in Slovenia by the law. If the mayor doesn’t say that it is a good idea, no changes will happen.”

Furthermore, each municipality can adopt its own legislation within the parameters of the Slovenian national law. This can complicate the implementation of specific EU programmes and makes them applicable to some municipalities but not to others.

“Because Slovenia has only two administrative levels - the national with the ministries and the local with the municipalities and there are 210 municipalities, it means they don’t have to cooperate. They really have autonomy. And it is difficult because some of them are very small. [...] And it’s very difficult to make some bigger development projects and take care of the regional development, as it is called from a EU position.”

The lack of a regional governance structure not only affects Slovenia’s ability to apply for EU funding, it also hampers its efforts to conduct EU programmes efficiently and to the highest benefit of the country and its people. It was suggested that there are multiple examples within the Podravje statistical region alone where EU funds have been wasted or misused at a municipality level and are now at a risk of claw-back because there was no intermediate body to evaluate and supervise the appropriate use of the funds. This leads to the hypothesis that a more administratively potent regional governance level could positively influence the access to funding and the efficient distribution and use of energy efficiency funds. The adoption of a more decentralised governance approach by establishing regional governance bodies might further positively influence the sustainability of the country and the efficacy of funding and investment, not only directly related to energy efficiency but concerning the transposition and monitoring of any EU directives and policies.

Governance and the transposition of EU law into Slovenian law

Nieboer et al. found in their international study on energy efficiency in housing management that almost all of the 11 investigated EU countries stress “the combination of national, regional and municipality activities” (Nieboer et al., 2011, p. 3). Slovenia is no exception to this, with EU and national legislation being transposed into regional and local level programmes. However, Sitar et al. (2009) note that Slovenia is struggling to keep pace with EU strategies in preparing legislation, regulation and methods for energy efficiency and renewables. While EU legislation tends to be adopted and integrated into Slovenian law in a timely fashion, it is the practical application that is often faced with resistance or incapacity:

“For example, we already talked about the energy certificates for buildings in 2006 and 2007, and they only came into force in the last year, in July 2013. So 7 years we were talking about the energy certificates that were already in the energy law in Slovenia in 2006. So then if I’m a citizen I will say “Ah, they are ten years ahead of the things. So if they are now talking about some inspection of the
boilers they will think, maybe it will come into force in Slovenia in 10 years because we are so many years behind the European practice.”

After its independence in the early 90s, Slovenia began to implement a range of EU directives “with the intention of harmonising national legislation” (Sitar and Krmelj 2014, p. 243). Some of these laws were transposed into national energy law but others were assimilated into a range of other ministerial documents and sectors. This led to a fragmentation of laws and responsibilities across several separate governmental departments. So was the EU Energy Performance of Buildings Directive (2002) transposed into four separate Slovenian laws, falling under the jurisdiction of the Ministries of Environment, Infrastructure and Spatial Planning (fig. 1).

![EU Energy Efficiency Policy](image)

**Figure 1 - Main EU and Slovenian Energy Efficiency Policy (Source: Own image based on Sitar and Krmelj in Jones, P., Lang, W., Patterson, J. & Geyer, P 2014).**

The themes of sustainability and energy have featured increasingly in Slovenia’s legislation since the start of the new millennium. A number of important documents were adopted as illustrated in the policy timeline in figure 2, such as the National Energy Programme (2004), the Energy Act (2005) and the Development Strategy of Slovenia (2005) with a focus on sustainability and energy-saving (Sitar and Krmelj 2014). Sitar et al. (2009) highlight that energy efficiency in buildings made a relatively late appearance in Slovenian legislation in 2008. The increasing relevance and pressure to promote energy saving and energy efficiency in combination with the need to facilitate the implementation of energy policies led to the establishment of EU co-financed local level energy agencies in 2006. Both the adoption of the National Energy Efficiency Action Plan 2008-2016 which established energy efficiency measures for new and existing buildings, and the Local Energy Concept were linked to and supported by those agencies which became heavily involved with the practicalities of the policies and their translation into local-level programmes. In the Podravje region for instance, the energy agency was involved in the development of Maribor’s Local Energy Concept.

With no common approach or national strategy on energy efficiency in buildings until 2008, the retrofitting of the existing building stock had been left to the individual owners and the municipalities (Sitar et al. 2009). This situation proved the lack of an applied regional governance body to be a
problem. A body of this kind could otherwise have acted as a bridge between the national and the local municipality level and facilitated the translation of the existing national building laws into tangible local projects. The existing statistical regional governance structure, however, had no administrative power to interact in such a way between the national and local level.

Figure 2 - Slovenian Sustainability and Energy Efficiency Policy (source: own image based on Sijanec 2009).

EU legislation and policies have had a strong influence on Slovenia’s energy efficiency efforts in the built environment over the last decade of its membership, and are directing it towards a more harmonised policy landscape. This has meant a rapid change to comply with EU objectives and little time for the country to adapt. At an end-user level, it was found that this could foster irritation and resistance due to conflicting messages from the media and the public sector, which has also struggled to keep pace.

“The priorities some years ago were different; there was nobody to explain that renewable energy is important and that it is the future. The marketing was just for fossil fuels and in favour to pollution, everything in favour to pollution, not energy efficiency. And so the public is now confused and doesn’t want to accept the new European legislation about this.”

In addition, EU policies are often seen as imposed on the country as an obligation rather than being a “product of dialogue” (Sadakata 2006, p. 45). As a result, EU legislation is adopted into the Slovenian legal system promptly to satisfy the European Commission, but its actual application tends to occur only when necessary.

“I have to be familiar with the EU legislation and our Slovene legislation because we are in the European Union and this must be implemented. But the Slovene legislation is tricky; everything works on paper but nothing in reality. It is very, very hard to deal with it.”

A lack of urgency to enforce EU policies in practice at the national level translates directly to the end-user level, where the EU is perceived to add to an already confusing and overly administrative body of national law.

“We have too much legislation on paper and it’s a chaos because one is for that and another is for that and if you wanted to do something you must look for this and this and that legislation, and if you use this one then you cannot use that one and it’s as I said chaos in some areas.”

The perception among some interviewees was that applying this growing body of energy efficiency and sustainability legislation is “too hard” and often unproductive, making passiveness the preferred option among end-users. Moreover, it has been suggested that a frequently unstable government which has on average changed every two years and high levels of corruption in the government and public sector foster an attitude of economic self-interest in the population and a strong grey market economy (Transparency International 2014). One respondent suggested that, unfortunately, this stretches across a range of levels of Slovenian society:
“Everyone is doing something for themselves or alone. There is no cooperation between the actors and it’s hard to arrange some cooperation between the municipality and the companies, even the bank - it’s not possible.”

**European Union funding**

The European Union is a major provider of funding for Slovenia and the country receives significant funds from the European Regional Development Fund and the Cohesion Fund. It is difficult to overstate the importance of these funds for Slovenia, particularly in light of the still perceptible repercussions of the European financial crisis. Public sector budgets have been significantly cut as part of the country’s austerity measures and Slovenia was struggling with high levels of unemployment due to unprecedented numbers of bankruptcies in the private sector. Beside the national level, municipalities were also largely unable to provide funding for energy efficiency, leaving the EU as the biggest energy efficiency investor for the country.

Slovenia has successfully applied for and received significant EU funding for sustainability and energy efficiency-related programmes and projects. In the last years, though, it has become clear that some of those projects are not reaching their potential or are failing to achieve agreed targets. Where this has not already occurred, these projects will likely been seen as failures or as an inappropriate use for the funding. If the EU programme audits find fault with those projects, this could lead the EU to withholding further funding and even potential future claw-backs:

“We've already lost [a substantial amount of funding]! But it is even worse because we will have to pay back I think. I know the EU rules very well, and it is not a system that says "if you have not worked well, just leave it, you won't get more money but we will forget about your faults." No, they won't. We will have to report and give the money back.”

As it is, the decision-making power for the local projects lies with the mayors and municipalities. A regional supervising body might put the national level in a much better position to prevent or mitigate the misallocation of funds for projects which fail to meet agreed energy efficiency and performance targets.

**Conclusion**

There are several issues which currently could prevent Slovenia from reaching the energy efficiency potential for its built environment. The main issues that have been identified are governance and funding issues, with governance standing out as the most far-reaching for Slovenia as a country. The lack of an administrative regional governance level is an obstacle for the effective transposition of EU energy efficiency policy and its translation to useful energy efficiency programmes in the built environment at the local level. And while Slovenia appears to have a large body of laws and regulations on energy efficiency, there remain gaps particularly in areas related to housing and energy efficiency. Furthermore, while EU directives are adopted in a timely manner, they may be integrated into the existing laws and regulations in a fragmented way, making their application confusing and inefficient.

Not only does the absence of a regional administrative level appear to have an impact on Slovenia accessing and allocating funding from EU programmes, but also on the quality and energy efficiency performance of the projects which are built through the support of this funding. This holds not only financial and reputational risks for Slovenia’s public sector but equally carries motivational implications for its population. With a history of regions based only on statistical and economic considerations, current expectations of governance standardisation by the EU, and a local governance level which fosters competition rather than cooperation between the municipalities, it appears that a strengthening of the regional governance through the establishment of a supervisory or administrative body might enhance Slovenia’s efforts towards a more energy efficient and sustainable built environment. On a European level, it may be time for a rethinking of regional governance as an integral level in the governance chain to achieving EU carbon reduction targets.
Acknowledgements

This paper has been made possible through the funding and support of the COST Action Smart Energy Region and their award of a Short-term scientific mission (STSM) grant. The data collection was part of a PhD research project at the Welsh School of Architecture in Cardiff, funded by an EPSRC doctoral scholarship allocated through the Retrofit 2050 project (EPSRC-funded) under supervision of Prof. Malcolm Eames and Prof. Peter Pearson. The researcher gratefully acknowledges the support of EnergaP, the energy agency of the Podravje region, as STSM host and thanks all interviewees for their time and generosity in sharing their knowledge and experience. The author is solely responsible for all views expressed in this paper.

References


From smart cities to smart regions – a field report

Ingrid Kaltenegger 1, Morten Elle 2

1) JOANNEUM RESEARCH Forschungsgesellschaft mbH, Elisabethstrasse 20/II, 8010 Graz, Austria. Email: Ingrid.kaltenegger@joanneum.at
2) Center for Design, Innovation and Sustainable Transition (DIST), Aalborg University – Copenhagen, A. C. Meyers Vaenge 15, DK – 2450 Copenhagen SV. Email: elle@plan.aau.dk

Abstract: Cities house 60% of the world’s population. In contrary to common belief, urban systems can be more sustainable than rural or suburban areas. When a city is dense, people and resources are close to each other, and energy can be saved when ways are short. Densely populated cities can also be a source of innovation when human capital is concentrated on a relatively small area. A so-called “smart” or sustainable city is characterized by using innovation solutions mainly linked to the investment in technology to address burgeoning municipal problems, like retrofitting of building stock, smart energy grids, electric vehicle charging infrastructure, installation of heat networks, onsite renewable energy generation, etc.

Literature proofs that in some cases smart cities grow together to smart regions, addressing similar topics but on a bigger scale. One example is the Öresund region with Copenhagen and Malmö as the two main cities. The municipalities of Copenhagen and Malmö have been known for quite some time for their efforts in their own towns but also for their joint efforts in the Oresund Region to become a smart region.

A short-term scientific mission (STSM) within the COST Action TU1104 was used to investigate the transfer of knowledge from these smart cities into the region surrounding them. The activities of the STSM focussed on:

• identifying success factors and barriers for smart cities and regions;
• exploring successful policy strategies for cities and regions in different topics of smart cities;
• gaining know-how in the transfer of knowledge from cities to their surrounding region;
• documenting good practices and success stories.

Keywords: smart cities and regions, cross-border, Öresund Region, good practices

Introduction

Many cities but also regions have tried to create a “green and sustainable” image to become more attractive for people, investors and enterprises during the past years (Anderberg, Clark, n.d.). A good example for that are Copenhagen and Malmö, together with the Öresund Region that surrounds the two cities. When the so-called Öresund cooperation was launched in 1994, it was one of the central visions to become one of the cleanest big city regions in Europe (Anderberg, Clark, n.d.). The building of the bridge across the Sund, connecting Denmark and Sweden and opened in 2000, was of great support to that idea.

Copenhagen and Malmö have often been mentioned as fore-runners in the context of smart, sustainable or eco-cities with their sustainability profiles and eco-branding strategies (Anderberg, Clark, n.d.). What characterize a smart or sustainable city or region are innovative solutions mainly linked to the investment in technology or infrastructure to address municipal problems, e.g. smart energy grids, smart mobility, but also the design of new, smart districts.
In this paper, some examples for smart innovations in Copenhagen as well as in Malmö and their impact on the whole Öresund Region are described and analysed.

**Methodology**

A short-term scientific mission (STSM) within the COST Action TU1104 was used to investigate the transfer of knowledge from the smart cities Copenhagen and Malmö to each other and into the region surrounding them. The activities focused on:

- documenting good practices and success stories;
- exploring successful policy strategies for cities and regions in different topics of smart cities;
- gaining know-how in the transfer of knowledge from cities to their surrounding region;
- identifying success factors and barriers for smart cities and regions.

The projects and initiatives that are explained in more detail in this paper have been explored during the STSM via interviews with people working in these projects and initiatives and excursions on-site but also with people from Aalborg University Copenhagen, so this paper combines a more distant observation from outside with an insight look.

**Good Practices and Success Stories**

**The Öresund/Greater Copenhagen Region**

The region can be defined as the part of Denmark East of the Great Belt and the Swedish Region Skåne with in total about 3.5 million inhabitants. The region has been called the ‘Öresund Region’ for quite some time, but recently it has been decided to use the name ‘Greater Copenhagen’ starting from January 1st 2016 (City of Copenhagen, 2015). The two main cities in the region are Copenhagen and Malmö. The city of Copenhagen has some 1.3 million inhabitants including the suburbs, 1.8 million inhabitants in the entire metropolitan area. The Municipality of Copenhagen covers most of the central part of the city with around 590.000 inhabitants as of September 2015 (Statistics Denmark, 2015). The Municipality of Malmö has around 318.000 inhabitants (ultimo 2014) with some 690.000 inhabitants in Greater Malmö as of the beginning of 2015 (Statistics Sweden, 2015).

![Figure 1 - “Clickable” Map of North Zealand and the Öresund Region (Source: http://www.highrise.dircon.co.uk/deptlads/cph99/index.htm).](image-url)
Copenhagen

When Copenhagen is presented as a smart city, emphasis is put on things like the Harbor Baths (using the clean water in Copenhagen Harbor), the bicycle infrastructure and the wind turbines providing the city with electricity (http://www.smartcityexpo.com/en/copenhagen-smart-city). It was however the municipality’s use of big-data that made Copenhagen win the World Smart Cities award in 2014 (http://www.investindk.com/News-and-events/News/2014/Copenhagen-Wins-Smart-City-Award). The Municipality of Copenhagen has the ambition of being the world’s first CO\textsubscript{2} neutral city in 2025, and has developed a plan how to achieve this goal (City of Copenhagen, 2012). In the following, the projects mentioned above are described in more detail.

Middelgrunden windfarm

This project is an example of a large cooperative, an innovative way of locating wind turbines and an innovative way of financing the initial stages of a project. The idea of having a windfarm in the sea near Copenhagen originates from the Copenhagen Environment and Energy Office (KMEK), one of the many local environment and energy offices – related to the Danish Sustainable Energy NGO OVE, carrying out local activities. KMEK took the initiative to create Middelgrunden in 1996, with the idea in mind to create a large cooperative. The Middelgrunden Wind Turbine Cooperative was founded in May 1997, with initially approximately 1.000 members. In the following years, the KMEK office contacted between 50.000 and 100.000 citizens, and 10.000 people bought 30.000 pre-subscriptions. Each pre-subscription meant approx. 7 € funding for the project’s at the planning stage – an innovative way of funding the initial stage of the project, which would have been difficult to finance in other ways (KMEK, 2003). Citizens were later invited to buy shares in the wind turbines. In 2013 there were 8.420 people owning the 10 turbines (http://www.middelgrunden.dk). The Middelgrunden windfarm consists of 20 2MW turbines, Copenhagen Energy owns half of the turbines and the Middelgrunden Wind Turbine Cooperation owns the other half. KMEK played a central role not only in relation to organising the cooperative, but also in the actual design, taking care of the visual impact: the turbines are located close to Copenhagen Harbour – very visible when approaching the city from the North. The turbines are placed in a circular arc with a 12.5 km radius, with a total length of 3.4 kilometres (KMEK, 2003).

The Cycle Super Highway project (Supercykelsstier)

This is a collaborative, inter-municipal project in Copenhagen. In the suburban areas of Copenhagen cycling has traditionally been considered a mode of transport for short, intra-municipal trips. Bicycling in central Copenhagen has been developing since the early 1970s (Knudsen, Krag and Forbund, 2005). For longer distances, however, the tendency has been to reduce bicycle use and increase motorized transport, especially car use (Næss and Jensen, 2005). Therefore, the Cycle Super Highways project is
a direct attempt to change this tendency, supporting non-motorized transportation, and at the same
time to improve health and reduce emissions. The City of Copenhagen has been eager to promote
inter-municipal commuting on bicycle in order to get even more commuter traffic on bicycle in the
city, which is part of the City of Copenhagen’s visions for a CO₂ neutral city. The Cycle Super Highway
is coordinated by an independent secretariat, funded by the participating municipalities, the Capital
Region and the Road Directorate of Denmark. Some 20 municipalities in the region participate in the
project. The objective of the project is to build 500 kilometres of high quality cycle paths in order to
provide citizens with the possibility of transporting themselves on bicycles across the city
(http://www.supercykelstier.dk/hvad-er-en-supercykelsti).

Bicycle parking

Bicycle parking is an issue emerging with the increased number of bicyclists. Providing good parking is
a part of encouraging citizens to use the bicycle, and easy parking is one of the major advantages using
a bicycle instead of a car in the central part of town. Bicycle parking is seen as a major challenge on
both sides of the Öresund, especially in connection with transport infrastructure hubs like railway and
metro-stations. The differences between Copenhagen and Malmö become clear when ‘smart’ bicycle
parking is discussed. Smart bicycle parking was discussed as a part of the Öresund Smart City Hub
project (http://www oresundskomiteen org klimat 1 4-interregprojekt oresund-smart-city-hub).

Smart bicycle parking would provide the bicyclist information about the nearest vacant bicycle stand.
In Malmö this is considered as very useful information, whereas it is considered too troublesome to
use a smartphone for looking for bicycle parking in Copenhagen. One of the important differences is
in the legislation: in Malmö you get fined and your bicycle is removed, if it is parked illegally outside a
designated stand. In Copenhagen it is impossible to make this sort of regulation, even though
anarchistic bicycle is found annoying in Copenhagen as well. Bicycle parking has to be fast,
uncomplicated and convenient in order to make the bicycle competitive (Öresund Smart City Hub and
Aalborg Universitet København, 2015).

Malmö

“In 2020 Malmö will be a flourishing and leading knowledge, demonstration and development centre
for sustainable development. Those who live and work in Malmö will enjoy a city environment with
clean air and low noise level” Municipality of Malmö, 2009). The four overall environmental objectives
for the city of Malmö are:

• Malmö is Sweden’s most climate smart city;
• the urban environment of the future is in Malmö;
• natural resources are managed sustainably in Malmö;
• in Malmö it is easy to do it right.

By 2020, the city’s organisation is to be climate neutral and by 2030, all of Malmö will be 100%
sustained by renewable energy. So also Malmö puts in a lot of efforts to become a sustainable and
smart city. Some of the projects are described shortly in the following.

Hyllie

Hyllie is a new, sustainable city district in the city of Malmö, which will offer 9,000 homes and almost
the same number of jobs when fully developed. It is planned that people from both Denmark and
Sweden can live and work here, as the connections between both countries are great.

In February of 2011, the City of Malmö, E.ON and the municipal authority VA SYD signed a climate
contract for Hyllie. Under this contract, the foundation was laid for Hyllie to become Öresund regions’
most climate-smart city district and a global benchmark for sustainable urban development. Hyllie is
a kind of a laboratory to test and develop the concepts that will serve as a role model for Malmö’s
continued progress as a sustainable city (Municipality of Malmö, 2015a). In 2020, Hyllie will be 100% sustained by renewable or re-used energy. The renewable energy is derived from wind, sun and biofuels and will be produced locally (solar cells on the properties, biofuel based district heating) or regionally (wind power). The re-used energy comprises energy recycling from waste and wastewater, which will generate district heating, electricity and biogas. Furthermore, mandatory sorting of food waste, urban gardening, sustainable travel, environmentally certified office buildings, and green rooftops will be part of the success of Hyllie to become a smart city district. Hyllie is also a good example where the city government and planners learned from other examples, such as “Bo01”, the Western Harbour Project in Malmö, where a lot of things have started and been successful but which also had/has its deficiencies (http://www.hyllie.com/in-english.aspx).

Augustenborg

In August 2014, Malmö faced one of the worst violent storms and cloudbursts. One of the neighbourhoods that was significantly better off than others in Malmö was Augustenborg. Due to the old sewage drainage system, Augustenborg used to suffer from annually floodings. Frequently, underground garages and basements were damaged and access to local roads and footpaths had to be restricted. In addition to that, untreated sewage also often entered watercourses as a result of increasing pressure on the sewage treatment works (http://climate-adapt.eea.europa.eu/viewmeasure?ace_measure_id=3311#challenges_anchor).

Then, from 1998 to 2002, a regeneration of the whole area was done: a sustainable urban drainage system (SUDS) was built up, including 6km of water channels and ten retention ponds. The rainwater from roofs, roads and car parks is now channelled through trenches, ditches, ponds and wetlands, with only the surplus being directed into a conventional sewer system. Green roofs have been installed on all developments built after 1998, and retrofitted on 10,000 square meters on an existing building.

One of the success factors was the extensive public consultation, including regular meetings, community workshops, and informal gatherings at sports and cultural events. Approximately one fifth of the tenants in the area have participated in dialogue meetings about the project, and some have become very active in the development of the area. Constant communication and in-depth community involvement enabled the project to accommodate residents’ concerns and preferences regarding the design of the storm-water system. Consequently, the project encountered little opposition (Municipality of Malmö, 2015b).
Urban farming

In 2014, Malmö adopted a comprehensive urban farming program to get a better overview on the numerous initiatives that were set throughout Malmö over the last years. Allotment gardens have been in place during the last years but also communal gardens and a new arena for city gardening emerged in some of the suburbs. The local farming cooperative is the coordinator for city streets and parks departments and focuses on experimental cultivation as well as on the educational direction of schools and kindergartens. For example, in Lindeängelund, plantation terraces were created, together with display gardens to inspire schools and kindergartens. “Edible farming” is one of the main themes as well as new and innovative solutions to make gardening possible for everyone. The idea behind is to make it easy for people to take some seeds and cultivate a piece of land spontaneously. The tools for doing so are already on site, they can be borrowed and also tips and tricks can be exchanged with other people there. “The whole concept of Lindängelund and the terraces is to inspire and to educate, as well as spreading the idea of sustainability, and right now we are focusing a lot on children and youth”, says project manager Lisa Hirsch. Plans are already there for a future city farm, where healthy animals would be living in an urban environment, including bees, worms in compost and maybe chickens and quails. Not far from Lindängelund, there is Malmö’s first forest garden Mullbärsbacken (Mullberry Hill), with trees, shrubs and perennials, many of them edible, using the sustainable cycle of the forest itself as a model. The whole area of Lindängelund will be developed until 2020 into a city park, with a botanical garden, allotments, a lake, forests and meadows - an exciting place to make excursions to.

Joint efforts in the region

Copenhagen and Malmö are at the moment reinventing themselves. Both cities have a similar history, being coined by heavy industry for a long time, followed by an economic decline in the 1970is and 1980is. Copenhagen and Malmö define themselves as smart cities of the 21st century and both cities are ranked among the most innovative cities of the world. Since 2000 the two cities have been linked by the Öresund Bridge. In 2007, some 25 million trips were made across the Sund, which was about twice as many as in 2001 (Anderberg, Clark, n.d.).

Many contacts have been built over the last years and some (bigger) projects have been started or elaborated over the last years:

- A joint wind park is planned; there is a strong common interest for such a project, which would be unique as it would combine 2 countries in their efforts to push renewable energies forward.

- The Öresund Smart City Hub is a Swedish-Danish collaboration project including municipalities, regions, universities and cluster organisations on both sides of Öresund. It was planned as a clean-tech focused cross-border innovation platform. The cities/municipalities on both sides of the Sund all have ambitious climate strategies but are also facing several challenges to reach their visions. Until the start of the project in 2012, there has been little notion of cross-border collaboration. In order to increase the competitiveness of the whole region, the project aimed at bringing together partners from private and public as well as knowledge institutions to explore innovation opportunities. The overall aim of the project was to create a permanent cross-border innovation platform enabling innovation partnerships with focus on green growth, clean-tech and smart city solutions.

- A number of municipalities in the Öresund Region were engaged in developing and implementing ambitious strategies and objectives linked to sustainable urban development, the “Urban Transition project” (an INTERREG Project). This project is again a cross-border cooperation between Swedish and Danish partners (academic institutions and local governments) in the Öresund Region on the topic of Sustainable Urban Development. In total, 10 actors in the region have created an experimental and case-oriented project: the municipalities of Lund, Malmö, Copenhagen, Ballerup and Roskilde, Lund University, Malmö University, Roskilde University, Aalborg University
Copenhagen and the Swedish University of Agricultural Sciences. Within three main themes (sustainable planning processes, guidelines for sustainable construction and sustainable finance for new urban areas as well as retrofitting), cross-border methods and tools for sustainable urban development have been developed. The project focused on case studies in Denmark as well as Sweden, supplemented by research on international experiences. The project also tried to give suggestions on how new forms of cooperation can promote the transition into a more sustainable urban development. More information can be found on the webpage of the project: http://www.urban-transition.org/urban-transition-oresund.

Analysis

The different cases and success stories could show that there are many examples for city projects on both sides of the Öresund that work with new approaches and technologies and also reach out into the region and the other city. All examples have their own focus and their own success factor: Hyllie in Sweden can be seen as a kind of laboratory for all kinds of technologies on the way to a smart and sustainable city. Middelgrunden Windfarm in Denmark as well as Augustenborg in Sweden could show the positive effect of early and intensive involvement of citizens. Also the Urban Farming project in Sweden is based on early involvement and information of citizens, as early as in Kindergartens and schools. The Cycle Super Highway project is an approach to better link the city of Copenhagen with the surrounding region.

There are also problems and issues that concern the cities on both sides of the Sund like the bicycle parking. But this issue also shows that the fact, that national regulations are different in the two countries, is a barrier for direct transfer of solutions.

Finally, the Urban Transition Project as well as the Öresund Smart City Hub indicate that cross-border cooperation have a positive potential, probably as they had a very specific focus on that issue.

Success factors that could be identified are:

- There has been close connections between Denmark and Sweden before the bridge, but it is clear that the Öresund Bridge made the two cities grow together even more. People are commuting more and living and working on both sides of the bridge.

- It seems that all this development is especially beneficial for Malmö, as it almost became part of a capital.

- Both cities have a very high environmental profile nowadays; Malmö can be seen as the “little brother/little sister” of Copenhagen. Both cities also have a similar history; similarities can bring the two cities more together.

- Both cities can offer something to the other city and get inspiration from each other.

- The cities have a shared vision in terms of smartness and sustainable development and there is already close cooperation in some projects.

- Furthermore, both countries are working on removing fiscal and legislative barriers that still hinder cooperation in a certain sense.

- There are already some joint projects the “Urban Transition” project was mentioned by all interviewees as THE example. The will for a regional development, also cross-border is obvious.

But there is also a lot of competition between the two cities and some obstacles and barriers:

- Collaboration is not that easy as we are talking about two countries, with different legislation, different languages, different currencies and also with different focal points and approaches, even if these countries have always been very close.
• Sweden is, although so close, a “foreign country” for a lot of Danish people and probably vice versa as well. There are meetings and knowledge exchange/sharing, but collaboration strongly depends on departments and people. This is a way to get inspiration from each other, but when it comes down to project it can become difficult.

• the Öresund Region never became a real brand, now we are talking about the “Greater Copenhagen Region” and it is the question if Malmö is happy about that and finds niches to further develop.

• The region consists of more than only Malmö and Copenhagen, also other cities are involved alongside the Sund.

• The regional level, at least in Sweden is rather weak, and is also not that much explored yet.

• It seems that also Stockholm is not really interested in seeing a strong collaboration between Copenhagen and Malmö grow.

Conclusions

During the STSM it became obvious that there are a lot of interesting examples on smart city approaches and tools on both sides of the Öresund. Many of these examples are, however, not directly linked to the region but initiatives undertaken separately in the two countries. It also became rather clear that a smart city approach, although started in a region where preconditions at least seemed to be ideal for transferring it to the region around, is not at all easy to transfer. This leaves room for further cross-border cooperation as well as for an increased and enhanced regional transfer of knowledge and a combination of both.

The cases presented here were mainly based on practical experiences gained during the STSM, but more emphasis could also be put on a more scientific approach, putting one question in the focus: how can we (positively) use differences in the approach and learning process and see them rather as chances and not as a threat.

References

Anderberg, S., Clark, E.: Green Sustainable Öresund Region – Ecobranding Copenhagen and Malmö, n.d.
City of Copenhagen: CPH Climate Plan 2025, 2012
City of Copenhagen: Forslag til Københavns Kommune Kommuneplan, 2015
Municipality of Malmö: Befolkningsbokslut 2014,
Municipality of Malmö: Environmental Programme for the City of Malmö 2009 – 2020, 2009
Municipality of Malmö: Sustainable City Malmö, 2015a, 2015b
Statistics Denmark, 2015
Statistics Sweden, 2015
Internet links

http://www.middelgrunden.dk [Accessed 5 January 2016]
http://www.urban-transition.org/urban-transition-oresund [Accessed 5 January 2016]
Energy efficiency programmes in the spotlight - Analysis of governmental, institutional and entrepreneurial energy efficiency programmes: target groups, governance mechanisms and factors of success

Evelyn Lobsiger-Kägi, Vicente Carabias-Hütter
Institute of Sustainable Development, ZHAW Zurich University of Applied Sciences
Corresponding author: Evelyn Lobsiger-Kägi, kaev@zhaw.ch

Abstract: To be sustainable, life styles will have to adapt to low energy use (European Commission 2009), an effort which needs to be supported by energy efficiency programmes as well. Energy efficiency means providing the same benefit (output) with less energy input. This can be achieved by adoption of existing, more efficient technologies and energy system solutions or by an optimized matching of energy supply and demand. To foster application of these technologies and behaviours in households, administrations and companies, it requires incentives such as taxes, grants or on-site advice by experts. The initiators of such energy efficiency programmes are diverse: national or regional administrations or institutions, but also energy service companies (ESCO) or financial service companies.

How do these programmes work, who is addressed by whom and what are innovative models of such programs? Our desk research about energy efficiency programs in selected OECD-countries analyses target groups, governance mechanisms, factors of success and shows innovative programmes of the different initiators mentioned above.

Working together with other institutions for the setup and operation of an energy efficiency programme is important. According to our findings, this could be done better, especially from the national initiator’s side. Architects and construction companies are rarely appealed by any of the initiators and facility owners and maintenance staff only by ESCOs. In general ESCOs very often have programmes, which are a combination of governance mechanisms, which would probably be effective in programmes of national and regional institutions as well.

Introduction

Achieving a transition towards sustainable development is one of the most important challenges to modern society. Finding solutions requires not only a shift in technology, but also a shift in behaviour and business models. Long-term energy scenarios show that current life styles in industrialised countries are not sustainable on a worldwide scale. Existing technologies can in the short-run substantially reduce energy consumption and greenhouse gas emissions, but diffusion of technologies without corresponding practice cannot bring about the needed energy revolution. They have to be accompanied by policy measures, business initiatives and behavioural changes. To be sustainable, life styles will have to adapt to low energy use (European Commission 2009), an effort which needs to be supported by energy efficiency programmes as well.

Energy efficiency means providing the same benefit (output) with less energy input. This can be achieved by adoption and the right use of existing, more efficient technologies and energy system solutions or by an optimized matching of electricity supply and demand. Optimized matching will be more and more important as the share of renewable energies in the electricity grid increases.
Investments by households and companies will have to play a major role in this energy system transformation. Greater access to capital for households and SMEs and innovative business models are crucial. In general, energy efficiency has to be included in a wide range of economic activities from, for example, IT systems development to standards for consumer appliances. So there are many different types of actors, who can contribute with their behaviour or investments to a more efficient energy system: the house owner can install a more efficient fridge, a city can install more efficient street lights and a canteen operator can educate its staff about efficient cooking. To foster application of these technologies and behaviours in households, administrations and companies, it requires incentives such as taxes, grants or on-site advice by experts. The initiators of such energy efficiency programmes are diverse: national or regional administrations or institutions, but also energy service companies (ESCO) or financial service companies.

How do such energy efficiency programmes work, what are the governance mechanisms behind them and which ones are applied the most? Are there mechanisms, which are hardly ever applied? Which target group is addressed by which initiator of an efficiency programme and which target groups are maybe never addressed by such programmes? Furthermore, we want to show innovative programmes of national and regional initiators, as of these kinds of programmes already exist a lot, but many of them are very similar. At the end we develop ideas for successful and innovative efficiency programmes for regions.

The goal of this analysis is to show potentials in improving energy efficiency promotion. Therefore we will first have a look at the factors of success of such programmes to compare it with our analysis.

**Factors of success of energy efficiency programmes**

An important attempt that can improve effectiveness of these approaches seems to be to combine or bridge complementary programmes with a certain amount of overlapping (e.g. direct and indirect approaches to the same topic) (Jollands et al. 2009, p 38). Another potential to enhance success of the programmes is the interaction of different types of promoters of the same programme (e.g. EU-funded programmes are promoted also by national or local so-called Energy Info Centres or national programmes, which are supported also by commercial associations) (Rieder & Walker 2009, p. 39).

For the different programme mechanisms certain factors of success exist, which help programmes to be successful in their implementation. Rieder & Walker (2009) made a comprehensive overview about the reasonable design of different programme types (see table 1).

*Table 1: Factors of success of different governance mechanisms of energy efficiency programmes (Rieder & Walker 2009, p. 5-6).*

<table>
<thead>
<tr>
<th>Governance mechanism</th>
<th>Concept: factors of success</th>
<th>Implementation: factors of success</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Normative measures</td>
<td>Reasonable level of set standard, possibility to adapt standard over time</td>
<td>Controls and sanctions</td>
</tr>
<tr>
<td>• financial measures</td>
<td>Height of incentive is crucial, avoidance of lock-in phenomenon</td>
<td>Flexible adaption of fees, control and monitoring due to avoid lock-in phenomenon</td>
</tr>
<tr>
<td>• fiscal measures in regard to prices and tariffs</td>
<td>Specific for target group, targets must be formulated</td>
<td>Closeness to target group through audits, consulting, long-term application for high coverage</td>
</tr>
<tr>
<td>• informative measures</td>
<td>Seek Win-Win Situations through involvement of different structures</td>
<td>Permanent activation of target group, keeping critical distance to target group</td>
</tr>
<tr>
<td>• information, education, training</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• voluntary agreements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• social planning, organisational measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• cooperative measures</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

Proceedings of the International Conference 'Smart Energy Regions'
Cardiff, UK, 11th and 12th February 2016
Methodology

To gain an overview of energy efficiency efforts an inventory of energy efficiency programmes considering their operating contexts has been made. We considered programmes of electricity and heat efficiency.

As a starting point for our research we developed a model of understanding (see fig. 1) to gain insights in the field of energy efficiency and to visualize connections of the different stakeholders, means, framework conditions and targets of efficiency and demand side management. Within this model we examined possible initiators (green), regulation mechanisms (light orange, square) and infrastructures to be influenced (orange, round) with what objectives. Arrows define the flow from one compartment to the other. For example, a national administration decides about a change of legislation, which regulates electricity demanding infrastructure, such as prohibition of conventional light bulbs, which reduces energy demand, because the energy-saving lamp is more efficient. This framework helped us to perform a literature research about possible energy efficiency programmes, as we encountered all possibilities to promote energy efficiency.

Based on the framework we defined more concrete criteria to analyse the energy efficiency programmes (see table 2). The focus of our research is on different kinds of target groups and stakeholders of demand side management programmes: (a) consumers, (b) SME owners, managers, employees and suppliers (c) architects and construction companies, (d) facility owners, managers and maintenance staff, (e) financial services, (f) municipalities and regional administrations. The governance mechanisms of the programmes are categorized by the system of Pehnt (2010), replenished with one category out of our research experience during the project (voluntary agreements) and one category added because of our special focus on Energy Service Companies (ESCO) (Products and Services).
Table 2 - Categorisation of governance mechanisms by Pehnt (2010) complemented by the authors.

<table>
<thead>
<tr>
<th>Governance Mechanism</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normative measures</td>
<td>Energy efficiency directives for construction and refurbishments</td>
</tr>
<tr>
<td>Informative measures</td>
<td>Efficiency labelling systems for household appliances and light sources</td>
</tr>
<tr>
<td>Financial measures</td>
<td>Low-interest loans for energy efficiency measures</td>
</tr>
<tr>
<td>Fiscal measures and in regard to prices and tariffs</td>
<td>Environmental taxes and tariffs (eco-taxes, legal fees)</td>
</tr>
<tr>
<td>Information, education, training</td>
<td>Campaigns for awareness rising, education and information</td>
</tr>
<tr>
<td>Cooperative measures</td>
<td>Cooperative procurement for specific hardware or infrastructure</td>
</tr>
<tr>
<td>Measures regarding infrastructure</td>
<td>Implementation of an energy efficient heat distribution system in a community</td>
</tr>
<tr>
<td>Social planning, organisational measures</td>
<td>Citizen participation in the development of energy efficiency solutions</td>
</tr>
<tr>
<td>Products and Services</td>
<td>ESCO offering an energy service (e.g. 20 degrees in my flat during one year) at a given price and fulfilling it with greater efficiency, because of better long-term investment possibilities of an ESCO.</td>
</tr>
<tr>
<td>Voluntary agreements</td>
<td>Voluntary agreement on energy efficiency target as a motivation and obligation to fulfil it.</td>
</tr>
<tr>
<td>Others</td>
<td>i.e. trading of energy efficiency certificates, non-classified policy measures</td>
</tr>
</tbody>
</table>

To learn from the experiences of these existing programmes we analysed their outcomes and lessons learned to give recommendations for successful future energy efficiency programmes. Furthermore, it was also examined if a programme is organised not only by one main initiator but has a partner institution, which helps to promote and operate the programme.

Analysis of national and regional programmes

On this basis we started our research about energy efficiency programmes, where the initiator was the national administration in the following countries: Austria, Canada, Denmark, EU, Finland, France, Germany, Japan, Netherlands, New Zealand, Sweden, Switzerland, UK, USA. We conducted a desk research in governmental publications, academic publications, existing databases (e.g. EU-initiatives like MURE), meta-studies about programmes/instruments (e.g. IEA DSM Task publications), websites and actual magazines for evolving and innovative approaches. Moreover, DSM-programmes, where the initiator was a municipality or a regional stakeholder, were analysed in the following countries: Austria, Germany, New Zealand, Switzerland, UK.

Analysis of Programmes / Services of Energy Service Companies (ESCOs)

When speaking about energy services, it is of importance to agree on common definitions of the terminology used, let alone in view of the fact that the notion is understood differently depending in which context or literature used. First of all, what are “energy services”? Seefeldt et al. (2013) specify energy services as „activity offered through an external service provider based on the basis of a contract, which lead in general to verifiable and measurable efficiency improvements or primary energy savings” and furthermore “energy services can include different services such as information, advice, planning, financing, investment, implementation, operation and maintenance, energy procurement and measurement and invoicing.” This detailed description is also in line with the definition made in Directive 2006/32/EC of the European Parliament and other found during literature research made. The latter refers to energy service companies (ESCO’s) as “a natural or legal person that delivers energy services and / or other energy efficiency improvement measures in a user’s facility or premises, and accepts some degree of financial risk in so doing. The payment for the services delivered is based (either wholly or in part) on the achievement of energy efficiency improvements and on the meeting of the other agreed performance criteria”.


Figure 2 - Value chain from energy services (adapted from Renner 2012).

Fig. 2 shows the value chain from energy services and gives an overview of the different consecutive steps leading to a desired result or product. Usually, energy performance contracting includes most of the steps shown here, although there are contract and service providers who cover only parts or even single steps of the process chain (Renner 2012). For instance, some service providers may only offer consultancy and advice, others only the financing and so forth.

Three main categories of services are provided by ESCOs. By means of Energy performance contracting (EPC), savings in energy demand guaranteed by an ESCO are to be achieved. The financial savings generated by the implemented technology and on-going verification is used to cover the costs for the project and capital cost. Customers hence don’t need to provide the investment capital upfront. Energy services provider companies (ESPC’s) or Energy Supply Service Companies on the other hand “provide a service for a fixed fee or as added value to the supply of equipment or energy”, such as heat or compressed air. Services include therefore the purchase of fuels and might be comparable with cogeneration and district heating.

At Delivery Contracting (DC) or Supply Contracting provided by ESCO’s (or ESPC’s), energy in form of electricity, heat (for example from cogeneration) or simply as primary fuel is provided. Electricity from renewable sources may also be included as a specific product.

Predominantly, the categorisations of the services in this study have been done according to a division proposed by Pehnt (2010) as shown in Tab. 2. In addition to the categorisation according to Pehnt (Tab. 2), we evaluate the position of energy services inside the value chain (cf. fig. 2).

When comparing both the categorisation system according to Pehnt (2010) with the value chain shown from Renner in fig. 2 one fact is particularly apparent: The policy categorisation system covers only certain, specific aspects and services, whereas the analysis performed shows that these services are rarely offered as a stand-alone product; rather they are included in a whole range of services. This conclusion is also conformed in a cross-country analysis performed by Labanca (2010).

Results of the analysis of national programmes

In total 73 programmes were collected and analysed according to the criteria mentioned above. Eleven of these programmes have a partner institution to help in the promotion and operation of the programme. We conducted an analysis about target groups and governance mechanisms of the programmes. Fig. 3 shows the percentage of the analysed programmes, which are designed for the respective target group.
The main target groups of national programmes are consumer/households, SME owners and municipalities/regional administrations. Facility owners are also an important group to target on. Most programmes are tailored to a target group, there are only very few addressing all energy consumer. Architects and construction companies are not very often approached by national administration, although they have a quite big influence on the way buildings are constructed and how energy efficient they are.

Fig. 4 shows the percentage of the analysed programmes with the respective governance mechanisms (multiple mechanisms per programme are possible).
Information/education/training, financial measures and advice/consulting are the most important mechanisms. Surprisingly normative and informative measures, such as labelling, are not very common, although if these measures should be established it usually had to be on the national level.

It was also examined if a programme is organised not only by one main initiator but has a partner institution, which helps to promote and operate the programme. We also identified programmes, which are innovative in some way. All these identified programmes have in our opinion an uncommon and promising approach. Table 3 shows these programmes with their respective innovative aspects.

**Table 3: Innovative programmes of national initiators.**

<table>
<thead>
<tr>
<th>Name of Programme</th>
<th>Country</th>
<th>Target Group</th>
<th>Governance Mechanism</th>
<th>Description of the Mechanism</th>
<th>Innovative Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governmental Support for the Development of a 2000Watt-Society Concept (EnergieSchweiz für Gemeinden n.d.)</td>
<td>Switzerland</td>
<td>municipalities and regional administrations</td>
<td>advice, consulting</td>
<td>The Federal Department of Energy supports selected communities to develop a 2000-Watt-concept. Communities analyse their energy needs in the very different areas and their potential for local renewable energy production.</td>
<td>Long-term vision with a broad concept, which includes buildings food, transportation, lifestyles</td>
</tr>
<tr>
<td>Warm Front scheme (EEB 2011)</td>
<td>Great Britain</td>
<td>consumers and households</td>
<td>financial measures</td>
<td>This Government scheme is targeted at combating fuel poverty in the privately owned and rented property sector in England. It aims to make homes warmer, healthier and more energy efficient. The scheme consists of a grant and funds energy efficiency measures like more efficient heating systems, new insulation and draught proofing.</td>
<td>Specific target group of the programme are energy poors; health as an explicit motivation for action</td>
</tr>
<tr>
<td>GREEN FUND (Harvey 2014)</td>
<td>Great Britain</td>
<td>municipalities and regional administrations</td>
<td>financial measures</td>
<td>Government-backed green investment bank finances replacement of street lights with LED lights. Local authorities and other public bodies can receive the cash needed for the new lights upfront. They have to pay it back over time as they realise the efficiency savings from the new technology. The bank offers UK local authorities low-interest fixed-rate loans over a period of up to 20 years.</td>
<td>Cooperation between a bank and the national and in the end the local authorities</td>
</tr>
<tr>
<td>Federal Buildings Initiative (Natural Resources Canada n.d.)</td>
<td>Canada</td>
<td>national administration</td>
<td>advice, consulting</td>
<td>The Federal Buildings Initiative (FBI) is a voluntary programme that helps facilitate energy efficiency retrofit projects (in buildings owned or managed by the Government of Canada) that lead to reduced energy and water use, GHG emissions and operating costs. The FBI offers a set of services and products to help simplify and remove much of the risk of implementing a retrofit project.</td>
<td>National programme for national administrations; comprehensive information and training including industry contacts</td>
</tr>
<tr>
<td>Energy efficient schools guide (NZAEE n.d.)</td>
<td>New Zealand</td>
<td>facility owners, managers and maintenance staff</td>
<td>information, education, training</td>
<td>A guide with an energy-efficiency checklist that aims to motivate / encourage students, teachers and other actors in the school environment to take stock of the current energy situation in a school, to explore alternatives, to inspire change and to monitor the effects of this change (e.g. in behaviour). The aim is to involve the whole school in changing practices.</td>
<td>Target group is the school environment including teacher, students, facility managers, trustees</td>
</tr>
<tr>
<td>Name of Programme</td>
<td>Country</td>
<td>Target Group</td>
<td>Governance Mechanism</td>
<td>Description of the Mechanism</td>
<td>Innovative Aspects</td>
</tr>
<tr>
<td>-------------------</td>
<td>---------------</td>
<td>--------------</td>
<td>----------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td>Eco-Model Cities programme (Jollands et al. 2011)</td>
<td>Japan</td>
<td>municipalities and regional administrations</td>
<td>financial measures advice, consulting</td>
<td>One of the central goals of the programme is to create model sustainable cities that can be replicated across the country. EMC began with a competition open to every Japanese city, with selected cities receiving financial and advisory support from the national government in acknowledgement of their efforts. All cities participating are involved in a ceremony and receive a licence card, further adding to their public acknowledgment by the government.</td>
<td>Creation of model cities, that can be replicated</td>
</tr>
<tr>
<td>Energy saving obligation for energy companies (Energy Efficiency Watch 2013)</td>
<td>Denmark</td>
<td>SME owners, managers, employees and suppliers</td>
<td>normative measures</td>
<td>Energy companies in Denmark have to contribute their share to the attainment of the energy efficiency goals, which is ensured by an energy saving obligation. The overall objective of the scheme is that utility companies are to help increase the overall savings efforts, focusing on achieving energy savings in final energy consumption, which would not have been realised without the involvement of the companies. The utility companies have freedom of methodology in order to deliver savings in the most cost effective way.</td>
<td>Energy saving obligation to energy companies freedom of how to accomplish the obliged savings</td>
</tr>
<tr>
<td>Grants for outperforming standards (building sector) (Energy Efficiency Watch 2013)</td>
<td>Germany</td>
<td>facility owners, managers and maintenance staff</td>
<td>financial measures</td>
<td>Financial support via grants and soft loans is available for the construction of buildings outperforming standards.</td>
<td>Reward for outperforming buildings and not only for meeting the normative standards</td>
</tr>
<tr>
<td>Video Competition (as part of the Energy Neighbourhoods project) (EnergyNeighbourhoods n.d.)</td>
<td>European Union</td>
<td>consumers and households</td>
<td>others</td>
<td>Run as part of the wider, European Energy Neighbourhood project, there has been a film competition; an opportunity for all budding amateur film directors to produce a short 4 minute film on the topic of saving energy in the home.</td>
<td>Competition as an instrument to involve pupils self-made video clip as a mean of communication</td>
</tr>
</tbody>
</table>

Results of the analysis of regional programmes

In total 90 programmes were collected and analysed according to the criteria mentioned above. 64 of these programmes work together with a partner institution. We conducted an analysis about target groups and governance mechanisms of the programmes. Fig. 5 shows the percentage of the analysed programmes, which are designed for the respective target group.
Proceedings of the International Conference ‘Smart Energy Regions’
Cardiff, UK, 11th and 12th February 2016

Figure 5 - Percentage of programmes of municipalities or a regional stakeholder, which are designed for the different target groups (multiple target groups per programme are possible).

The highest amount of programmes are targeting at consumers and households directly; a lower amount at municipalities/regional administrations and SME owners. The target groups are quite similar as of national programmes with the exception of the high amount of regional programmes tailored to consumer and households.

Fig. 6 shows the percentage of the analysed programmes with the respective governance mechanisms (multiple mechanisms per programme are possible).

Figure 6 - Percentage of programmes of municipalities or a regional stakeholder with the respective governance mechanism (multiple governance mechanisms per programme are possible).

Financial measures are the most common mechanisms applied, followed by cooperative measures and advice/consulting. Cooperative measures are mostly collectives, who operate renewable energy infrastructure for regional consumption and have also pilot projects or advice or information regarding energy efficiency.
We also identified programmes, which are innovative in some way. All these identified programmes have in our opinion an uncommon and promising approach. Table 4 shows these programmes with their respective innovative aspects.

**Table 4 - Innovative programmes of regional initiators.**

<table>
<thead>
<tr>
<th>Name of Programme</th>
<th>Country</th>
<th>Target Group</th>
<th>Description of the Mechanism</th>
<th>Innovative Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement of Utilization Ratio (AEV n.d.)</td>
<td>Switzerland</td>
<td>SME owners, managers, employees and suppliers</td>
<td>The canton of Grison gives financial support for optimisation of industrial and commercial processes regarding energy efficiency. The only requirement is a proof that the measures leads to a 25% optimisation of efficiency.</td>
<td>Optimisation of industrial and commercial process regarding energy efficiency</td>
</tr>
<tr>
<td>Mobiecheck (BMUB n.d.)</td>
<td>Germany</td>
<td>consumers and households</td>
<td>The Mobiecheck is a webbased tool with information about energy efficient ICT and mobile devices and their energy efficient usage</td>
<td>Target group are young and technically oriented people</td>
</tr>
<tr>
<td>Climate Protection Plus: General CO2 Reduction Programme (Umweltministerium Baden-Württemberg n.d.)</td>
<td>Germany</td>
<td>SME owners, managers, employees and suppliers</td>
<td>Target of the programme is the energy-efficient rehabilitation of non-residential buildings through different measures. Despite other approaches so called energy efficiency roundtables were initiated. On these tables 10-15 companies try to find solutions for more energy efficient processes through sharing of experience and cooperation in some processes or infrastructures.</td>
<td>Energy efficiency roundtables to share and cooperate between companies</td>
</tr>
<tr>
<td>Smart Energy Challenge (Smart Energy Challenge n.d.)</td>
<td>New Zealand</td>
<td>consumers and households SME owners, managers, employees and suppliers</td>
<td>The Smart Energy Challenge supports projects that aim to reduce energy use and increase renewable energy in Wellington. It will help applicants by: &gt;Introducing to mentors which are relevant to your project &gt;Hosting workshops to develop the project conceptually, and to teach crowdfunding techniques &gt;Introducing to corporate partners where appropriate &gt;Boosting project’s profile through a number of media releases and public events &gt;Providing some match funding from Wellington City Council’s Smart Energy Capital Fund for the amount the crowd raises</td>
<td>Combination of: &gt; collaborative network &gt; youth-led organisation, with the central purpose of providing solutions for New Zealand to cut carbon pollution through smarter transport, liveable cities &amp; independence from fossil fuels &gt; crowd funding</td>
</tr>
<tr>
<td>Waikato Regional Energy Strategy (Environment Waikato 2009)</td>
<td>New Zealand</td>
<td>municipalities and regional administrations</td>
<td>The overall purpose of the Waikato Regional Energy Strategy is to: &gt; encourage and enable energy conservation and efficiency &gt; promote the Waikato region’s role in maintaining security of energy supply &gt; facilitate the development and use of renewable energy sources and innovative energy technologies &gt; acknowledge and promote the crucial role of energy in the regional and national economy.</td>
<td>Very detailed strategy for one region</td>
</tr>
</tbody>
</table>

**Results of the analysis of programmes provided by Energy Service Companies**

A total of 52 different programmes have been selected, described and categorised as specified. Ten of these programmes work together with a partner institution to promote and operate the programme. The distribution in percentage on target groups as shown in Fig. 7 clearly points out that the main focus of energy services providers’ lies on facility owners, managers and maintenance staff (69%). Consumers and households (27%) and SME owners as target groups are currently of less interest for ESCOs. Other target groups such as financial services, architects and construction companies don’t appear as relevant in this study. This is however surprising, since a general awareness for retrofitting and energy efficient construction in this sector is observable.
Figure 7 - Percentage of programmes of ESCOs with the respective target groups (multiple target groups per programme are possible).

Quite often it seems not to be very clear, which specific governance mechanism applies for the examples examined. For instance, a specific reference may cover different mechanisms such as advice, consultancy; information, education, training and social planning / organisational measures. We therefore resorted with the most obvious governance mechanism specified.

Figure 8 - Percentage of programmes of ESCOs with the respective governance mechanism.

When comparing the overall numbers distribution of governance mechanisms, it becomes clear that the majority of energy service companies offer in particular advice and consulting (Fig. 8). However, in some cases companies offer consulting only as part of an overall service which is provided along the value chain shown in Fig. 2. Therefore, these provided services, cannot be regarded as stand-alone services. Rather, and quite often, they are the initial step inside the whole value chain discussed by Renner (2012), leading up to a desired implementation of energy efficiency measures.

Outcomes and lessons learned

For the further development of future energy efficiency programmes, it is useful to know the experience from existing or already closed programmes. The outcome in saved kWh or CO₂-emissions is measured – and at least published, as we only used public available information – only in very few programmes (in 24 of the total 215 analysed programmes). In other 30 programmes we found at least some information about the success of the programmes in terms of participation or actions taken, such as number of participants or number of conducted insulations. Based on this information, we couldn’t carry out an evaluation on the question, which programmes are the most successful ones,
because the data situation to perform that is too bad. Therefore we concentrate on the analysis of the stated lessons learned, as from these inputs we can at least give some recommendations for future programmes.

16 programmes published their experiences as lessons learned, unfortunately but understandable none of the ESCO-programmes did so. We found lessons learned in different areas: communication, programme mechanism, target groups and topics. The findings are structured in these areas and summed up in bullet points:

Communication:
- A trustworthy sender of the programme is a key factor for success;
- Use simple messages;
- A label for cities efforts is important;
- A label as a help for recognition for the population is important;
- One single contact person is for all target groups important (use even the same person for different programmes);
- For voluntary community activities, a funny and friendly accompanying campaign is useful.

Programme mechanism:
- Grants for infrastructure are a good possibility, but the grant programme has to be long lasting;
- Low loans for renovations combined with impartial advice is a good combination;
- Freedom to choose your favourite supplier (no regulations regarding suppliers as criteria for participation);
- No upfront-costs for households;
- Simple realisation for households;
- Immediate visible success for households (e.g. on energy bill).

Target groups:
- Energy poor as target groups are good to reach with free exchange of appliances;
- Addressing the broad population is difficult (even with mass media campaigns).

Topic:
- Voluntary measures work well, especially if there exists a possibly upcoming regulation on the respective topic;
- To tackle energy poverty, a programme should also look at the renovation of the target groups’ houses even if they live mostly in rented apartments.

This summary represents only a selected share of knowledge and experience from the programme providers, based on the publicly available information. Nonetheless, policy makers can profit from these recommendations, although the list is not exhaustive at all.

In general, we found only few critical statements on the programmes and overall – as already mentioned – very few programmes publishing any outcome evaluation. Probably a lot of them are not evaluated at all, which is unfortunately often the case in energy efficiency instruments (Harmelink et al., 2008).
Discussion

Following the recommendations regarding the factors of success (see above), it would be important to run a programme with one or several partner institutions. On the regional level, we already found a high share of programmes with partner initiators, but on the national level lots of programmes are not linked to another institution, which might increase the effect of a programme. Maybe for a region it might also be useful to look at the national programmes or at programmes of regional ESCOs and cooperate with them, instead of setting up an entirely new programme. Especially two different types of promoters are an efficient setup for a programme, therefore working together with an ESCO is certainly a good opportunity.

Another factor of success is to tackle one topic with different approaches that is governance mechanisms. We have seen in our analysis that different governance mechanisms are in use. We saw, on the regional level financial measures are the favourite ones, whereas information and consulting are not that important. Information campaigns are mostly run by national initiators and advice and training are often offered by ESCOs, whereupon advice from ESCO is often linked with other approaches like fiscal or financial measures or measures regarding infrastructure. Maybe it would be wise to coordinate the programmes of national, regional and ESCOs in a region to set up an efficient bunch of approaches on the same topic.

In general ESCOs very often have programmes, which are a combination of governance mechanisms, which would probably be effective in programmes of national and regional institutions as well.

There are a few target groups which are mainly addressed only from one side (regional, national or ESCO). For example facility owners and managers/maintenance staff are addressed by the ESCOs primarily. It would be reasonable that they would be approached also by other actors. Architects and construction companies in contrast are rarely appealed by any of the initiators. Although their knowledge and attitude are very important for the implementation of energy efficiency measures. This strong stakeholder should be kept in mind, when designing efficiency programmes.

A coordination and integration of the energy efficiency programmes offered at national and regional levels together with those provided by Energy Service Companies is highly recommended and encouraged to involve all stakeholders aiming at the same benefit (output) with less energy inputs.

Regarding approaches and motivational aspects the programmes work with, there are also some interesting similarities. Many programmes assume quite high interest in energy efficiency from their target audience and work with lots of information about what you could optimise. Especially for the target group of households this cannot be assumed for lots of them. Such programmes will result in the fact that always the same people engage and always the same people don’t participate. But exactly these households have probably a higher potential for energy efficiency than already sensitised households.

Looking at the very few public information on outcomes and lessons learned, we came to the same conclusion as Vine et al. (2012) that there is a need for more critical and scientific evaluation of energy efficiency programmes in order to learn from past experiences.

Acknowledgements

This work resulted thanks to the participation of experts and the research project C13.0147 Towards Smart Energy Regions funded by the Swiss State Secretariat for Education, Research and Innovation (SERI).

We thank Diego Sanchez for his contribution to the research about ESCO’s activities in energy efficiency.
References


EEB (European Environmental Bureau) 2011, Saving Energy in Europe: 15 Good Practice Case Studies, Brussels.


Energy Efficiency Watch 2013, Good practice ways out of energy debt, Brussels, Wuppertal, Cologne, Berlin, Linz


European Commission 2009, People, the economy and our planet - Sustainable development insights from socio-economic sciences and humanities. EUR 23053 EN. Brussels.


Renner, G 2012, Overall analysis and documentation of ChangeBest field tests of new energy efficiency services developed and introduced into the market in 16 EU Member States. Change Best, Cologne.


Influence of incentives, occupancy and energy-related behaviours on renovation strategies decision making

Stephane Monfils, Jean-Marie Hauglustaine
University of Liege, Belgium
Corresponding author: Stephane Monfils, stephane.monfils@ulg.ac.be

Abstract: The European policy for energy consumption and greenhouse gases emission reductions has imposed, in its 2002/91/CE Directive, the certification of any existing building’s energy performance that witnesses its energy consumption and efficiency, when it is sold or rented. That Energy Performance Certification (EPC) calculated with a standardized approach which purposefully (and understandably) gets human factor out of the equations, aims at influencing real-estate market by introducing energy efficiency as a comparative criterion in the search for a dwelling and stimulating energy saving investments. So far, the influence of the EPC has been negligible however: often distant from reality, overestimating the consumption, it results is a general misunderstanding, misuse or non-use of the document.

Furthermore, the EPC offers recommendations to the reader in order to reduce consumption; what appears however, is an automatic response to EPCs inputs, such as “insulate your roof” when no insulation is present or visible there, or “change the windows” when single glazing is still present. Assessors cannot tailor these recommendations to the particular house they are assessing, or to the household, its needs and desires for its dwellings. It is not even designed to offer financial or economical advice on renovation strategies, and appears, therefore, uninformative on the cost or potential impacts on the consumption.

The following questions arise naturally: how can the EPC reach this goal? How can it become a decision-helping tool that would actually be used by real-estate enthusiasts? Previous studies have shown that implementing real occupancy and energy-related behaviour parameters in the regulatory calculation method can help close the gap between theoretical and real energy consumption. This study takes one more step by integrating financial incentives and occupants strategic planning in the energy and economic performance assessment of progressive renovation scenarios, focusing on two urban single-family houses, chosen for their representation of the Belgian urban residential stock. The aim of this study is to develop decision-helping routines that take into consideration economic and energy performances of renovation strategies, occupancy scheme and energy-related behaviours, potential incentives and occupants’ budgets and preferences, whether they relate to comfort, materials or strategies on the use of the dwelling.

Introduction

European Union’s strategy for a sustainable growth makes energy consumption reduction in the building sector a central objective for meeting the commitments taken under the climate change challenge. At a worldwide scale, this sector is thus regarded as one of the most cost-effective options for saving CO$_2$ emissions (IPCC, 2007). To target the existing buildings potential, the European Union introduced (through the 2002/91/CE European Directive) Energy Performance Certificates (EPC), which should provide clear information about the energy performance of a building when it is sold or rented, including reference values, allowing performance comparisons between buildings. The EPC should also include “clear” recommendations for technically possible improvements, in order to increase investments in energy efficiency, move the housing market towards greater energy
efficiency, influence real-estate market value and help built up comprehensive benchmarking databases, fundamental for shaping smart strategies on a local, regional and national level.

Given necessary standardization, the calculation method does not provide realistic results, and this is confirmed by energy bills; in theory, two different families living in two identical homes would receive identical EPCs, but in reality, their real consumption would vary from one to three or four (Hens, 2010), depending on occupants’ behaviour and household characteristics. As a consequence, crossing several studies that have been led in Belgium (Vanparys et al., 2012), the UK (Laine, 2011; O’Sullivan, 2007) or in Germany (Amecke, 2012) enlightens a general conclusion: the EPC is often considered unhelpful, unrealistic (and therefore mistrusted), distant from reality, overestimating consumption, too long and technical, confusing…

Sociology of energy points the lack of appropriation of results as a missed opportunity. This study is therefore based on the assumption that, though acknowledging the importance of a standardized approach to allow building comparisons, other and more accurate results could be obtained from EPC inputs, by closing the gap between theoretical and real consumptions. Previous papers (Monfils, 2014, Monfils 2015) listed the uncertainty parameters of the Walloon EPC protocol and calculation method, and proposed a method for the introduction of additional data (on the number of inhabitants, occupation patterns of the dwelling, levels and quality of electr(on)ic equipment and lighting) into a recalculation of internal gains, Net Heat Demand (NHD) and Domestic Hot Water (DHW) demand.

This paper will present a study where these calculation methods are applied to the assessment of two very typical Walloon urban houses, on their initial state and in the decision-making process of deep renovation. The first part describes the method, houses, households, a selection of renovation scenarios (with reference to owners requirements), and the criteria that will be used to compare the results. The second part presents results for both projects, both evaluated with the official standardized “default” calculation method and the proposed, “users included” method. Conclusions and discussions will compose the last parts of this paper.

Method

This study evaluates a selection of decision-making criteria for the renovation of two houses. These criteria have been selected to cover a range of habitual concerns:

- CO₂ emissions (considering only those related to energy consumption), in tons per year;
- Energy performance criterion (the specific primary energy consumption level – Espec – evaluated in kWh/m².yr) adding primary energy consumptions for heating, domestic hot water, auxiliaries and cooling (when appropriate), and withdrawing renewable supply.
- Financial criteria (using an Excel sheet, developed by EnergySuD for previous studies), considering the total cost of interventions, available financial incentives, a loan with progressive length and fixed interest rate, VAT, inflation and discount rates. The outputs are all given for a 20 years’ time span:
  - The energy bills, expressing energy consumption in a monthly cost of energy, instead of an annual sum of “kWh” of “primary energy”. Profitability is, therefore, easier to understand and closer to people concerns.
  - The available incentives (important part of owners’ renovation decision-making processes).
  - The cost of all interventions, without loan, alongside the corresponding available incentives. This cost does not consider necessary fitting, decoration, or any other work unrelated to energy performance.
  - The total cost on 20 years, which could be given with or without loan or incentives; we decided to consider both loan and incentives (most probable situation).
o The Net Present Value (NPV) of each case, representative of its profitability (if > 0).

- Comfort criteria:

  o Summer comfort evaluation is based on the overheating risk evaluation that already exists in the official calculation method.

  o Winter comfort is evaluated differently: a list of 4 priority comfort improvements is given by the owner (based on a list of typology usual weaknesses); if one of the 4 related interventions is conducted, the overall “winter comfort increase global index” will rise by 20% for the first priority, 15% for the second, etc., up to 50% for all 4 actions. The remaining half of this index reflects the improvement percentage of the Net Heat Demand (NHD) between the initial value and the minimal NHD attainable for the house. The NHD has been chosen for its accurate reflection of several important parameters of the winter comfort: envelope insulation (presence of cold walls), ventilation and airtightness related losses, internal and solar gains.

When facing the renovation of a house, infinite combination of interventions could be studied; the ones presented in this study have been selected among others in order to take owners requirements into consideration, as well as for their logical progression in the overall renovation of the houses. The cost of each scenario have been evaluated (sources: EnergySuD data bases for Reno2020, COZEB and SISAL research projects, UPA 2009), as well as the effects on the different decision-making criteria.

**Hypotheses**

This study concerns two typical Walloon houses, built before WWII and generally poorly insulated. Both households gave additional information on their levels (and use) of equipment, occupation and heating patterns, comfort habits and other pertinent data (that will not be described here) that allowed us to recalculate internal gains, net heating and domestic hot water demands for “users included” results, as described in (Monfils, 2014) and (Monfils, 2015).

![Figure 1 - Blue Collar (BC) house front façade and 3D front and back views of initial occupation pattern; the blue volume is the “night zone” (with bathroom in clearer); the red one, the “day zone”; circulations are in yellow.](image)
Figure 2 - Master (M) house front façade and 3D front and back views of initial occupation pattern; the blue volume is the “night zone” (with bathroom in clearer); the red one, the “day zone”; circulations are in yellow. White zones are unused and unheated.

Figure 1 presents the modest “blue-collar” house (~ 18 to 20% of Walloon dwellings), characterized by simple architecture, small spaces and general bad condition – especially the annex at the rear. The dwelling contains, on the ground floor, a living room, circulation spaces, basement access, a toilet, and a kitchen in the annex; the upper floors of the main volume contain 3 (small) bedrooms and a bathroom. It is inhabited by a family of four; one of the parents works outside the house during the week, the other stays at home to care for their smallest child while the second child attends school. After renovation, the occupation pattern is likely to change, as the “stay-at-home” parent will take a half-time job back.

The four sources of winter discomfort given by the owners are the windows (simple glazing and high infiltration rate), the basement-adjacent walls (cold walls), the need for more light in the top floor (skylights), and the heating production system, old and weak. Among other important information and requirements are the low renovation budget (€50.000, with the necessary loan), the simplicity of building operation (programmable regulation) and the need to occupy (most of) the building during operations, which lowers the number of possible solutions. Difficult access to the rear façade and urban planning constraints also play a role in the present scenarios selection.

The second house (see figure 2) is similar to the first but presents superior size and architectural quality (“master house”), especially on the front façade, which makes outside intervention impossible. The annex is generally in the same (bad) condition; in this case, it leans on half the width of the rear façade, on two levels (with a bedroom above the kitchen). The dwelling initially contains 3 bedrooms, and the top floor is unused (and un-usable without important fitting); the owners, a family of 5, wish to invest this space, in order to create two bedrooms and an additional bathroom, and to enlarge the parents’ bedroom on the lower floor (see figure 3). The building is usually heated following children school schedule during the week.

Sources of discomfort also find an echo in the blue collar house, as windows, basement-adjacent walls and bad heating production system are pointed out as problematic. In this case, though, the main discomfort comes from the attic, uninsulated and highly “ventilated”. The maximal budget is €100.000, from which 20.000 have to be withdrawn for necessary interior fitting, the new bathroom and other non-performance related works. The same difficulties arise, as far as urban planning regulations and access to the backyard are concerned.
Figure 3 - Master house 3D front and back views of final occupation pattern; the blue volume is the “night zone” (with bathroom in clearer); the red one, the “day zone”; circulations are in yellow. White zones are unused and unheated.

For both dwellings, a series of renovation works has been proposed: for each renovation case, the improvement (when compared to the previous case) has been highlighted in the Table1.

The first few renovation works (steps 2 to 7 for the first, 2 to 8 for the second) present a progressive insulation of the protected volume, the installation of a ventilation system and of new heating and DHW production systems, with respect to the owners’ priorities and requirements. Cases 8 (for the first; 9 for the second) to 10 see some variations in the previous cases (heat pump, all mechanical ventilation system with heat recovery). The third part (cases 11 and 12) shows an increase (level 2) of the insulation of cases 9 and 10, which are yet furthermore insulated (level 3 ≈ passive recommended level) in cases 13 and 14. Case 15 displays the results for a pellets boiler for heating system, combined with solar systems (also present in cases 13 and 14).

The financial hypotheses are as follows:

- Inflation rate: 1,5% (source: Federal Planning Bureau, for 2014)
- Mortgage loan rate: 2,5%
- VAT on renovation works and pellets: 6%
- VAT on fossil fuels and electricity: 21%
- Discount rate: 4% (source: Federal Public Service Finances)
- Initial energy prices per kWh: pellets: €0,056; natural gas (NG): €0,066; electricity: €0,212 (day) / €0,1272 (night) (source: Renouvelle magazine, June 2015)
- Scenario of price evolution: 1,75%/yr (moderate)
- The length of the loans are progressively increased from 5 to 20 years, so as to keep a monthly payment below €400 (for the blue collar house) or €500 (for the master house, except for the last 3 cases where the payments rise to €600 to €700 per month to keep the loan at 20 years max.).
### Table 1 - Proposed renovation case options for both blue-collar and master houses

<table>
<thead>
<tr>
<th>Units</th>
<th>Base</th>
<th>Renovation cases</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue collar house</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protected volume</td>
<td>m³</td>
<td>505</td>
<td>686</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heated floor area</td>
<td>m²</td>
<td>150</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td>W/m²K</td>
<td>5.3</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td>W/m²K</td>
<td>4.2</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front facade</td>
<td>W/m²K</td>
<td>2.4</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rear facade</td>
<td>W/m²K</td>
<td>2.4</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annex facade</td>
<td>W/m²K</td>
<td>3.3</td>
<td>3.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tilted roof</td>
<td>W/m²K</td>
<td>2.4</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat annex roof</td>
<td>W/m²K</td>
<td>2.2</td>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor on basement</td>
<td></td>
<td>1.7</td>
<td>1.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annex floor (on ground)</td>
<td></td>
<td>0.7</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stairs (on basement)</td>
<td></td>
<td>1.6</td>
<td>1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basement-adjacent wall 1</td>
<td></td>
<td>2.2</td>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basement-adjacent wall 2</td>
<td></td>
<td>2.6</td>
<td>2.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average U-value</td>
<td>W/m²K</td>
<td>1.57</td>
<td>1.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f50 (air tightness)</td>
<td>m³/h.m²</td>
<td>12.9</td>
<td>9.72</td>
<td>6.6</td>
<td>5.4</td>
<td>3.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Ventilation system</td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating system</td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global efficiency (PE)</td>
<td></td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>Domestic Hot Water system</td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global efficiency (PE)</td>
<td></td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Thermal solar installation</td>
<td>m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>PV solar installation</td>
<td>kWc</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

### Master house

<table>
<thead>
<tr>
<th>Units</th>
<th>Base</th>
<th>Renovation cases</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protected volume</td>
<td>m³</td>
<td>505</td>
<td>686</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heated floor area</td>
<td>m²</td>
<td>150</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td>W/m²K</td>
<td>5.3</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td>W/m²K</td>
<td>4.2</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front facade</td>
<td>W/m²K</td>
<td>2.4</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rear facade</td>
<td>W/m²K</td>
<td>2.4</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annex facade</td>
<td>W/m²K</td>
<td>3.3</td>
<td>3.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tilted roof</td>
<td>W/m²K</td>
<td>2.4</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat annex roof</td>
<td>W/m²K</td>
<td>2.2</td>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor on basement</td>
<td></td>
<td>1.7</td>
<td>1.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annex floor (on ground)</td>
<td></td>
<td>0.7</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stairs (on basement)</td>
<td></td>
<td>1.7</td>
<td>1.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basement-adjacent wall 1</td>
<td></td>
<td>2.2</td>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basement-adjacent wall 2</td>
<td></td>
<td>2.6</td>
<td>2.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average U-value</td>
<td>W/m²K</td>
<td>2.07</td>
<td>1.73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f50 (air tightness)</td>
<td>m³/h.m²</td>
<td>12.9</td>
<td>9.72</td>
<td>6.6</td>
<td>5.4</td>
<td>3.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Ventilation system</td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating system</td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global efficiency (PE)</td>
<td></td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>Domestic Hot Water system</td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global efficiency (PE)</td>
<td></td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Thermal solar installation</td>
<td>m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>PV solar installation</td>
<td>kWc</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

1. No intervention possible from the outside or inside without important costs and urban planning constraints; considered unprofitable.
2. The roof initially contained 6 cm of old mineral wool; only insulation for the whole envelope.
3. No intervention possible from the basement (low ceiling); no intervention possible for both from the upper floor (costs, dwelling in use...).
4. C = semi-mechanical ventilation system (natural supply, mechanical exhaust); D = all mechanical ventilation system with heat recovery.
5. 1 = old natural gas boiler; 2 = new condensing natural gas boiler; 3 = air-water heat pump (COP=4); 4 = pellet boiler; 5 = DHW electric boiler.
6. PE = Primary energy; primary energy conversion factors are 1 for fossil fuels and biomass and 2.5 for electricity.
7. Some windows already presented (old) double glazing; first case only considered replacement of single glazed windows.
8. Intervention is possible from the inside, as works can be carried out room by room.
Results

The results for the blue collar house are displayed in Table 2 below; the results for the master house are listed in Table 3. The first half of each Table displays “default” results (using the official standardized calculation method for EPC results), while the second half presents “users” results (using additional behavioural data and heating patterns to introduce human factor in the equations of that steady state calculation method). For each performance criterion, renovation cases have been classified to distinguish worst results (black cells) from best results (white cells): the clearer the cell, the better the result.

In a complete and exhaustive case study, other scenarios would be displayed outside this organized guiding thread, proposing different renovation scenarios and/or different technical/technological solutions. As it is to be expected from this selection, scenarios displayed here see global gradual improvement of CO$_2$ emissions, energy performance and (winter) comfort index. Actually, among non-financial criteria, only the overheating risk does not gain from deep renovation works, but this is a logical result from added insulation and air tightness.

Despite a progressive increase in intervention costs and available incentives (identical in “default” and “users” methods), energy bills and total costs on 20 years, and NPVs, do not seem to follow the same simple logical progression, and therefore bring obvious complication to the renovation scenarios assessment. Most ambitious renovation scenarios (cases 13 to 15 in both houses) get top scores in all but those aspects, and should be discarded on first analysis, due to costs above the owners’ limit and clear unprofitability (in both “users” and “default” methods). Still, it appears possible to target less ambitious, but profitable, renovation scenarios below the maximum budget, in the “moderate” cases (7 to 12). In a similar fashion, less ambitious projects (cases 1 to 4) do not appear profitable, due to high renovation costs and low energy gains.

The official (“default”) calculation method usually overestimates the NHD of a dwelling, but it also appears to underestimate the Domestic Hot Water (DHW) demands, with the protected volume as only evaluation parameter. “Users-included” calculations, on the other hand, present lower NHD (thanks to lower set temperatures, higher internal gains, shorter heating periods...) and higher DHW demands. Therefore, detrimental default efficiencies values exercise higher influence on the final DHW energy consumption, as can be seen in cases that propose electric heating of water for domestic purposes, with the added influences of high electricity primary energy conversion factor, high electricity prices and low incentives. This usually result in unprofitable solutions (where NPV < 0).

In “users” results, differences appear that must be noted (except for the cost of works and incentives, which remain the same in both methods):

- Projects are visibly evaluated with lower CO$_2$ emissions and energy consumption (“Espec” criterion); these criteria even present a less progressive evolution through the cases;
- Comfort index (winter comfort) is given higher figures here, due to lowered NHD. Summer comfort (“overheating” criteria) presents the same variation (higher figures) due to increased internal gains in “users” calculation method.
- Energy bills on 20 years appears to have increased, but only for cases that propose electric DHW production solutions (case 8 in the BCH project, cases 10 and 12 for both), resulting in negative NPVs.
Table 2 - Results for the blue collar house.

| Case | Av. U value | v50 | Vent. 1 | Heating | DHW | CO2 | Spec E kWh/m² | Comfort Increase | Over-heating | Cost of works | Incen-tives | E bills (20 yrs) | Cost on 20 | NPV |
|------|-------------|-----|---------|---------|-----|-----|--------------|-----------------|-------------|--------------|------------|---------------|-------------|------------|-----|
|      | W/m²K | m³/h | Syst. | - | Syst. | - | t/yr | % | % | € | € | € | € |
| 1    | 1.57 | 12 | 1 | 0.64 | 1 | 0.26 | 30 | 395 | 0% | 0.00% | 0 | 0 | 105,151 | 105,151,38 | 0 |
| 2    | 1.30 | 9.6 | 1 | 0.64 | 1 | 0.26 | 18.82 | 345 | 28.4% | 0.00% | 9,526 | 620 | 620 | 91,940 | 134,308,12 | 2,567 |
| 3    | 1.19 | 8.4 | 1 | 0.64 | 1 | 0.26 | 18.21 | 321 | 47.2% | 0.00% | 11,556 | 620 | 620 | 38,453 | 137,007,97 | 4,939 |
| 4    | 1.08 | 6 | 1 | 0.64 | 1 | 0.26 | 17.42 | 289 | 60.0% | 1.13% | 25,775 | 4,578 | 77,997 | 143,774,06 | 131 |
| 5    | 1.08 | 6 | 2 | 0.96 | 2 | 0.39 | 4.43 | 172 | 67.0% | 1.13% | 31,728 | 1,735 | 45,729 | 177,080,19 | 23,648 |
| 6    | 0.79 | 3 | 2 | 0.96 | 2 | 0.39 | 3.56 | 137 | 76.4% | 7.95% | 35,597 | 6,094 | 36,518 | 115,794,78 | 29,168 |
| 7    | 0.79 | 3 | 2 | 0.96 | 2 | 0.39 | 3.56 | 137 | 76.4% | 7.95% | 39,677 | 7,004 | 36,518 | 97,718,65 | 21,384 |
| 8    | 0.79 | 3 | 3 | 1.45 | 5 | 0.21 | 4.23 | 119 | 76.4% | 7.95% | 41,945 | 6,704 | 33,053 | 97,300,80 | 22,600 |
| 9    | 0.79 | 3 | 2 | 0.96 | 2 | 0.39 | 2.89 | 108 | 85.1% | 7.95% | 43,025 | 6,104 | 29,008 | 95,887,52 | 24,346 |
| 10   | 0.79 | 3 | 3 | 1.45 | 5 | 0.21 | 3.61 | 101 | 85.1% | 7.95% | 45,290 | 6,704 | 28,173 | 98,300,10 | 22,840 |
| 11   | 0.77 | 3 | 2 | 0.96 | 2 | 0.39 | 2.83 | 106 | 85.7% | 8.64% | 44,786 | 5,999 | 28,391 | 98,362,96 | 22,598 |
| 12   | 0.77 | 3 | 3 | 1.45 | 5 | 0.21 | 3.55 | 100 | 85.7% | 8.64% | 47,054 | 6,599 | 27,745 | 100,964,13 | 20,911 |
| 13'  | 0.71 | 3 | 2 | 0.96 | 2 | 0.39 | 2.51 | 93 | 87.0% | 1.91% | 65,267 | 7,554 | 25,013 | 105,444,27 | -3,666 |
| 14'  | 0.71 | 3 | 3 | 1.45 | 5 | 0.21 | 2.52 | 71 | 87.0% | 1.91% | 66,575 | 9,354 | 26,898 | 107,291,76 | -5,510 |
| 15'  | 0.71 | 3 | 4 | 0.95 | 5 | 0.21 | 0.00 | 77 | 87.0% | 1.91% | 70,925 | 10,054 | 25,133 | 110,691,65 | -9,005 |

1. C = semi-mechanical vent. system (natural supply, mechanical exhaust); D = all mechanical vent. system with heat recovery.
2. 1= old NG boiler; 2= new condensing NG boiler; 3= air-water heat pump (COP=4); 4= pellets boiler; 5= DHW electric boiler.
3. Global efficiency (primary energy); primary energy conversion factors are 1 for fossil fuels and biomass and 2.5 for electricity.
4. Case 13: 4m² of solar thermal panels; Case 14: 2kWe of PV panels; Case 15: 6m² of solar thermal panels + 2kWe of PV panels.
**Table 3 - Results for the master house.**

| Case | Av. U value W/m²K | v50 ≤ m²/h | Vent. 1 Syst. | Heating 2 Syst. | DHW 2 Syst. | CO2 [g/kWh] | Spec [m³/yr] | Comfort Increase % | Over-heating % | Cost of works € | Incentives € | E bills (20 yrs) € | Cost on 20 years € | NPV € |
|------|-------------------|------------|-------------|---------------|-------------|-------------|-------------|----------------|----------------|----------------|-------------|----------------|----------------|----------------|-------|
| 1    | 2.07              | 12         | 0.64        | 0.26          | 20.15       | 661         | 0%          | 0.00%          | 0%            | 211,584       | 211,584     | 46             | 0              | 0              | 0     |
| 2    | 1.73              | 9          | 0.64        | 0.26          | 17.82       | 450         | 28.1%       | 0.00%          | 0%            | 19,222        | 1,057       | 166,614        | 264,421        | 7,452 |
| 3    | 1.53              | 7.2        | C           | 0.64          | 16.42       | 411         | 48.2%       | 0.00%          | 0%            | 39,907        | 2,402       | 170,833        | 255,708        | -7,566 |
| 4    | 1.47              | 6          | C           | 0.64          | 14.75       | 395         | 60.1%       | 0.00%          | 0%            | 42,203        | 2,402       | 163,857        | 253,927        | -3,353 |
| 5    | 1.47              | 6          | C           | 0.26          | 9.38        | 233         | 65.1%       | 0.00%          | 0%            | 48,512        | 2,602       | 96,796         | 200,940        | 60,892 |
| 6    | 1.37              | 5.4        | C           | 0.26          | 3.85        | 220         | 67.6%       | 0.00%          | 0%            | 51,722        | 2,818       | 91,600         | 202,990        | 62,464 |
| 7    | 0.82              | 3.0        | C           | 0.26          | 6.09        | 149         | 81.9%       | 7.15%          | 0%            | 62,095        | 5,903       | 62,067         | 152,523        | 77,809 |
| 8    | 0.55              | 2.4        | D           | 0.26          | 3.92        | 92          | 94.3%       | 17.82%         | 0%            | 69,917        | 6,379       | 38,464         | 140,961        | 91,575 |
| 9    | 0.55              | 2.4        | D           | 0.5           | 5.29        | 95          | 94.3%       | 17.82%         | 0%            | 72,321        | 6,979       | 41,292         | 147,036        | 86,547 |
| 10   | 0.52              | 2.4        | D           | 0.15          | 5.17        | 93          | 95.0%       | 19.51%         | 0%            | 72,718        | 6,379       | 41,396         | 147,036        | 86,547 |
| 11   | 0.52              | 2.4        | D           | 0.15          | 5.17        | 93          | 95.0%       | 19.51%         | 0%            | 72,718        | 6,379       | 41,396         | 147,036        | 86,547 |
| 12   | 0.43              | 2.4        | D           | 0.15          | 5.85        | 118         | 81.9%       | 7.82%          | 0%            | 62,095        | 5,903       | 40,000         | 139,456        | 11,895 |
| 13   | 0.43              | 2.4        | D           | 0.15          | 5.85        | 118         | 81.9%       | 7.82%          | 0%            | 62,095        | 5,903       | 40,000         | 139,456        | 11,895 |
| 14   | 0.43              | 2.4        | D           | 0.15          | 5.85        | 118         | 81.9%       | 7.82%          | 0%            | 62,095        | 5,903       | 40,000         | 139,456        | 11,895 |
| 15   | 0.43              | 2.4        | D           | 0.15          | 5.85        | 118         | 81.9%       | 7.82%          | 0%            | 62,095        | 5,903       | 40,000         | 139,456        | 11,895 |

1. C = semi-mechanical ventilation system (natural supply, mechanical exhaust); D = all mechanical ventilation system with heat recovery.
2. 1= old NG boiler; 2 = new condensing NG boiler; 3 = air-water heat pump (COP=4); 4 = pellets boiler; 5 = DHW electric boiler.
3. Global efficiency (primary energy); primary energy conversion factors are 1 for fossil fuels and biomass and 2.5 for electricity.
4. Case 13: 6m² of solar thermal panels; Case 14: 3kWc of PV panels; Case 15: 8m² of solar thermal panels + 3kWc of PV panels.

NPVs presented above will obviously change if the loan or the incentives conditions are different. The graph hereunder (Figure 4) shows the evolution of NPVs for all 15 cases of the master house (the results are similar for the BCH), with the 4 upper curves (round marks) representing the “default” results, and the lower 4 (square marks), the “users” results. Each of these 4 curves represents a variation: with or without the loan, with or without the incentives. Tables 2 and 3 only present the results for the “with loan and incentives” variation.

The graph shows quite clearly the cost optimum situation: if ‘extreme” scenarios (cases 1 to 4, cases 12 to 15) seem to become unprofitable (NPV < 0) with “users” method, it could be acknowledged that there still exists profitable scenarios among more moderate choices.
Figure 4 - NPV evolution for 15 renovation cases of the Master house, showing discrepancies between the cases with or without loan or incentives, in the “default” and “users” method.

Discussion

Several precisions (Monfils, 2014; Monfils, 2015) must be added here, as they probably appear unclearly in the results:

- Some distortions may be found in the results due to the presence of uncertainty parameters in the EPC calculation method (other than standardization of users’ behaviour). For example, different assessors could find different results for the EPC of the same house, despite the “EPC protocol” that has been developed to avoid this problematic situation. In this particular case, all EPC assessments have been made by the same rigorous assessor to elude this difficulty.

- Results show the marks of important and disadvantageous default values (used for heating and DHW systems production efficiencies, for example). Most of these default values have been replaced, as the renovation scenarios progressed, by more accurate (yet still average, or theoretical) efficiencies, which tends to increase trust in the results as the renovation deepens.

- Climate also appears uncertain, especially in predictive simulations. In these simulations, the average climate for Liege for the years 2003 – 2013 was used. Heat Island Effect (urban increase of external temperature due to high rate of built areas, when compared to green and blue areas) has not been taken into account here, as it is yet undefined for Liege (and unsure, due to a relatively high percentage of green and blue areas).

- Results presented here derive from a “steady-state” calculation method that uses monthly average interior and exterior climates. Average set temperatures hide simplifications and, therefore, uncertainties; adaptive temperatures and fine heating regulation influences are invisible. Dynamic simulations would surely increase precision, but the purpose of this study is to find a way to use the existing EPC protocol, calculation method, inputs and outputs. Initial decisions that led to the actual EPC system have to be considered here.

- Rebound effect is the general exceeding of expected consumption that could occur after renovation, due to better comfort conditions. This remains difficult to quantify however, depending on households’ attitudes, behaviour and idea of comfort improvement (which can be shifted to
increased consumption outside of the house); rebound effect therefore seemed another uncertainty parameter to add to the others. Furthermore, the Walloon calculation method already usually overestimates consumptions, even if improved by the introduction of human factors.

“Users included” calculation method lowers the profitability of all renovation cases, as stated before, by the logical reduction of energy consumptions and, therefore, absolute gains. This situation has several consequences: first, it produces more accurate NPV results, which is important to owners in their decision-making. This is, in some ways, a better “cost optimum” validation: this more severe selectivity in scenarios can help sort out “best” ones more clearly than in “default” hypotheses. Thus, it narrows the range of profitable renovation scenarios, discarding those where the energy consumption reduction is not sufficient to compensate renovation costs (first few cases) and those where the renovation additional costs are too high to be compensated by corresponding energy consumption reductions (last few cases).

Parallel assessment of incentives and NPVs can be made under that light: reality shows that incentives, in Wallonia, are not high enough to render most ambitious renovation scenarios, profitable. Figure 4 highlights the importance of loans and incentives conditions: accurate incentives system and “green” loans could help support technologies and motivate the renovation market, allowing targeted scenarios to turn profitable.

The first few cases, in both projects, display the minimal set of works asked by the owners. In the blue collar (BCH) project, this means replacing all windows and doors (due to bad frame condition or airtightness issues), and placing a semi-mechanical ventilation system, which is hardly profitable in itself, in strict financial terms, thanks to low incentives and relatively low influence on the calculation method; interest lies in the increase of winter comfort. In the master house (MH) project, first case sees the insulation of the tilted roof and the extension of the protected volume to create new spaces, which, in itself increases by 30% the global comfort, as it is the first comfort-related priority work cited by the owners. Case 3 is similar to BCH case 2 (unprofitable change of windows). BCH Case 4 appears even less profitable, as it is about increasing an already existing insulation layer in the roof (this work has been considered here as it is supposed owners would benefit from the installation of skylights to do this). The improvement in energy performance stays low, nevertheless.

Analysing the results of these cases, one could argue that the unprofitability of some works is somewhat drowned into the global scenario profitability, and almost forces to envision deeper renovation (and, therefore, added costs). It still appears possible to have deep and (almost) complete renovation of the house for less than €50,000 (in this case, thanks to small surfaces, avoidance of unprofitable interventions on the front façade and inferior floors, and the possibility of a less costly intervention on the back façade and annex). Cases 7, 9 and 11 appear as “cost optimum” solutions in this context, with the common influence of the “cost optimum” intervention that is the use of a new (and regulated) natural gas condensing boiler for heat and DHW production.

Cases 13 to 15 should be discarded on first analysis, due to costs above the owners’ limit and clear unprofitability. It is however interesting to include them in the global analysis, and to notice that, though the increase in costs (due to level 3 of insulation and solar equipment) is too high to be returned in energy gains, lower risk of overheating, CO₂ emissions, energy bills and total costs on 20 years could be positive arguments to some owners against less ambitious renovation projects. Making a general weighting system is difficult, even among the priority list; a household’s balancing and weighing of criteria is personal.

Conclusion

It is important to remind that the goal of this study is not to replace the actual standardized method, as it is necessary to compare buildings on a common ground; the goal is to question the uncertainty parameters, and propose a complementary calculation, based on the existing inputs and outputs of the EPC, to allow better decision-making strategies for households, as far as their real-estate
ambitions are concerned. And from this point of view, the first important result is the closing of the gap between real and theoretical consumptions when users’ behaviour have been integrated in the calculation method (Monfils, 2014; Monfils, 2015).

In order to reach energy efficiency at any level, human factor is crucial: on one hand, efficient solutions (regarding transport, building energy consumptions, water and waste management...) have to be implemented by an intelligent decision-making authority who understands the complexity of the urban context and its impacts on environment. On the other hand, smart cities authorities need smart citizens, who are aware of their environmental impact, to use smart solutions to their full potential.

In the field of residential use of energy, people are therefore a crucial parameter of both the problem and its solution. When facing renovation works, dwelling owners should be consulted at every step of the project and included in assessments.

“It is becoming increasingly clear that the impact people have on the eventual performance of retrofitted dwellings is often greater than variations in the thickness of insulation or in the efficiencies of heating systems” (Tweed, 2013).

Though renovation budgets have been fixed by owners by considering maximal real-estate value that can be expected for this house, in that kind of neighbourhood, the added real-estate value does not always appear as an important financial criterion in decision-making. This, however, is a result difficult to enlighten: choice of renovation works cannot be the only influence on real-estate value, as it also depends on location, volumes, functional spaces distribution, or architectural quality. Available incentives and loans characteristics could also exercise an influence.

It is also important to note that real DHW needs fundamentally changed the profile of renovation scenarios NPVs, thanks to high electricity prices and low incentives. Though the “users included” calculation method lowers the profitability of all renovation cases, cost optimum scenarios still exist, even amongst ambitious ones (though the “row” configuration of both houses plays an important role here). It can be noted, however, that the “users included” calculation method highlights less ambitious renovation scenarios than “default” method (considering equal weighting systems between criteria).

If value-action or attitude-behaviour gaps are to be considered when interviewing energy consumers on their energy-related behaviour, it could also be considered in the decision-making process in renovation, where comfort considerations can challenge financial interests in some decisions. For example, the change of windows would hardly appear “profitable” in the strict financial sense, but still is the most applied renovation intervention, partly because single-glazing devalues real-estate value, partly because double glazing improves hygrothermal and acoustic conditions of the rooms.

Uncertainty on financial criteria and “value-action gap” regarding profitability, encourage to not let them lead all discussions when presenting possible scenarios to the owners, to consider them as important information but to press on interesting advantages of other criteria (which, often, are more accurate because based on less changing parameters than energy prices and loan interests).

Multi-criteria assessment could then be called to define global weighting factors between priority criteria, but it will not necessarily lead to appropriation of results, as it changes with every household (even if not the priority positions, at least the weighting factors to balance them), but it must be recognized that some criteria are important to many (like the search for comfort or the reduction of energy bills), whereas some criteria are only important to a few (like the environmental impact).

References


Session 2: Urban planning and infrastructure
Welsh and Romanian policies for transition towards low carbon mobility

Mihaela Condurat 1, Joanne Patterson 2

1) Technical University ‘Gheorghe Asachi’, Romania
2) Welsh School of Architecture, Cardiff University, Wales UK

Corresponding author: Mihaela Condurat, conduratmihaela@yahoo.com

Abstract: The paper presents a comparative analysis concerning the approaches taken by decision makers in the Welsh Government and North – East Region of Romania for the transition towards low carbon mobility, as well as the new technologies, tools and processes which support this transition. After defining the general concepts of low carbon mobility, specific strategies for improving the sustainability of a city and examples of good practices for the Regions will be provided. The results of recent research undertaken for the assessment of the environmental indicators of various supply chains and technologies which supports this transition will be presented. The Global Warming Potential expressed in terms of CO\textsubscript{2}e emissions of a cycle path have been evaluated by using a life cycle assessment (LCA) study performed with GaBi software. The results from these studies will be presented and specific recommendations concerning the use of various technologies for reducing the environmental impact of the transport system are given.

Keywords: low carbon mobility, environmental impact, life-cycle assessment, CO\textsubscript{2}e emissions, policy, transport sustainability.

General concepts of low carbon mobility for the transport system

Low carbon mobility can be defined through those actions related to the transportation system which leads to significantly reduced consumption of non-renewable resources and smaller quantities of greenhouse gas emissions in the atmosphere. These actions refer both to the new technologies and processes supporting the transition towards low carbon mobility, the policies used for their implementation, as well as the human behaviour and daily personal choices.

Further on it shall be made a description of the most important strategies and projects supporting this transition in the Welsh and North East Regions.

Low carbon mobility for the rolling stock

The measures for reducing GHG emission related with the fleet vehicles refers to fuel efficiency through the use of improved vehicle structures and engines and alternative fuels.

Enhancing fuel efficiency can be achieved by improving the aerodynamic characteristics, reducing the total weight of the vehicle and using high performance engines. The development of new polymers, composite materials and so-called "memory metals" which are more resilient and lighter comparable with conventional materials will also lead to substantial reductions in vehicle weight and quantities of burned fuel (Budd et al., 2013).

For a better driver information about de level of pollution produced by the car, a smart dashboard indicating CO\textsubscript{2} emission in real time can be install.

As an example of carbon efficient cars there is the Prius hybrid car running on petrol and electric powers having regenerative braking to allow that kinetic energy to be used to reduce wear and tear on the brake pads (Toyota, 2015). Another example of green car is represented by the plug-in car developed by the Tesla Motors, being equipped with dual chargers for an efficient refuelling the
vehicle at home and on road trips (Tesla, 2015). Using hydrogen as fuel, Toyota also has developed and produced fuel cell vehicles (FCV), their world’s first fuel cell vehicle for the mass market being the Mirai (Toyota, 2015).

Low carbon mobility for the management system

The management system aims specifically to optimize the overall performance of transportation systems by continuously improving the infrastructure in order to increase transport safety and to protect the environment. Using smart management systems will help reduce the journey time, remote monitoring of traffic and prevention and mitigation of climate change. In order for those smart systems to work, an overall integration of road and rail networks is required. The implementation of intelligent systems and will also allow energy monitoring and mapping of access to energy (The Royal Academy of Engineering, 2012).

Prevention and mitigation of traffic pollution can be achieved taking measures as traffic diversion from urban areas or placing junctions and crossings at a significant distance from residential areas. Closing vehicle traffic in dense and compact areas where there is a diversity of services, encourage the use of public transport, walking and cycling and thus promoting low carbon mobility (Patterson, 2014).

In the management system are included as well and the policies options (strategic options) as the implementation of stricter regulations on engine emissions, removal of subsidies and incentives that have a negative environmental impact, increasing environmental taxes, voluntary agreements, funding research programs and the substitution of road transport to other modes of transportation, as rail transport, buses, cycling and walking.

Policies for transition towards low carbon mobility

Policies taken by Welsh Assembly Government towards low carbon mobility

The most efficient strategy for a low carbon society is represented by modal shift towards public transport, cycling and walking. In order for public transport to become the citizens first alternative, initially they have to become the mode choice of the decision makers implementing corresponding urban policies promoting greener modes of transportation and enhancing the efficiency of public transport. As shown in Figure 1, in the decision making process it has to be taken into consideration the most significant characteristics of the transport mode, these influencing if a sustainable personal transport mode will be chosen by the citizens.

Figure 1 – The pillars of personal mobility (The UK Government's Business Taskforce on Sustainable Consumption and Production, 2008).

The United Kingdom has a long tradition considering in the decision-making processes the sustainable transport principles. In this respect, in 1977, the UK Government has issued the “Transport Policy White Paper”, which contained a number of strategies on how to increase and integrate cycling into the existing transport infrastructure. In 1989, the attention for cycling has shifted towards road network through the biggest road building program, “Roads for Prosperity”. The result of this program was a rapid increase in private car ownership, having, as an indirect effect, a bigger quantity of GHG...
emissions released in the atmosphere. Therefore, in 1994, the UK Government has published “The Sustainable Development Strategy” which emphasized the need for reducing the usage of vehicle fleet. Further, policies encouraging the development of cycling infrastructure and guidance have been released, as a response for the problems emerged from the use of fossil fuels, as “Planning Policy Guidance 6: Town Centres and Retail Development” from 1993 which stipulated the need for 10% reduction of town traffic through cycling, and the White Paper “A new deal for transport” from 1998, dealing mostly with safety issues for vulnerable road users including cyclist (Patterson, 2014).

The decisions relating energy policy are mostly centralized at UK level, but some policies can be issued by the regional government. In this regard, Welsh Assembly Government (WAG) has published a set of strategies for reducing energy consumption and supporting sustainable transportation means. Therefore, in 2005 was released an economic development strategy entitled “Wales: A Vibrant Economy” which provides an overview of the key drivers for improving transport infrastructure from an economic perspective. The key drivers moving forward sustainability in Wales have been identified as innovation, entrepreneurship, skills, investment and trade. This document was meant to carry on the principles stipulated in “Wales: A Better Country” from 2003 (WAG, 2005).

In 2009 has been released a document, “One Wales: One Planet” which provided a series of specific strategies to be implemented in different areas, as shown in Figure 2, in order to meet the CO\textsubscript{2} reduction targets and to improve the living condition of Wales citizens.

Figure 2 - The development scheme of the Welsh Assembly Government (WAG, 2009).

The main objective of the Welsh Government consists in making renewable energy the only kind of resources used within the lifetime of a generation. In order to accomplish this remarkable objective it is necessary to further develop common standards to provide guidance regarding the use of renewable energy source, to invest in innovation and research and to improve the communication and engagement, providing tools and support to help people chose to live in a sustainable manner.

Regarding transport, the measures taken by the Welsh Government towards low carbon mobility are represented by the implementation of Wales Transport Strategy (WTS) which encourages people to use more sustainable ways to travel. Thus, there will be applied some strategies to improve the reliability, frequency and accessibility of public transport. In this respect, the Sustainable Travel Town will also promote walking and cycling, Cardiff being the first city from Wales declared a Sustainable one (WAG, 2009).

**Policies for transition towards low carbon mobility taken in the North East Region of Romania**

The first step moving towards low carbon mobility taken by Iasi County Council and City Hall was building in 2002 a partnership addressing territorial-administrative units for a harmonized development and strengthening the competitive advantages of Iasi County. The opportunity of this approach has been based on GRASP program. Thus, Iasi Metropolitan Area has been established first in the country (2004), aiming to promote a sustainable development of the region (Iasi Metropolitan Association, 2009).
In 2007, the Iasi Administration published “ORIZONT 2020”, which stipulate the implementation of a “Plan for Urban Mobility” (Iasi City Hall, 2014), in order to decrease dependency on private cars occupancy, to increase the proportion of pedestrians, cyclists and to promote public transport. Within this project a series of extensive analysis have been conducted on the flow of vehicles throughout the city, the pavement condition of the roads, mobility alternatives and energetic resources used in the city. Also, it was envisaged the development and implementation of a smart traffic management system improving accessibility, traffic mobility and public transportation.

Another policy for a clean and efficient public transport was represented by the project “ARCHIMEDES” in the frame of CIVITAS initiation. The project involved the usage of 30 high capacity buses with alternative fuels (LPG). Traffic light systems have been developed on 15 intersections and 11 km of cycling path were constructed in Tudor Vladimirescu Street. Campaigns to promote public transport have been successfully implemented in schools (Iasi City Hall, 2008). Also, significant research in Universities of the North East Region is being carried out on the assimilation and implementation of new sources of energy in different fields, on the efficient use of various “cold” technologies in housing construction, transport vehicles and infrastructure. New modes of transportation including cycling routes and hybrid vehicles are encouraged to be used and implemented as a result of existing EU projects like CIVITAS, EFFECT (Andrei et al., 2014).

The use of bio-fuels and other renewable fuels was promoted through Government Decision HG 1844/2005 completed with HG456/2007 and, as a direct result, by the end of 2010, the percentage of biofuels in total energy usage for transportation sectors being 5.75%.

An important milestone in the sustainable development of Iasi County was publication of “The Integrated Development Plan of Iasi Growth Pole 2009-2015” where goals for economic and social competitiveness have been set. To ensure traffic flow within the municipality it was initiated and carried out an extensive process of Capital Repairs of some passages and bridges on the road network which presented a faulty technical state. Also, in 2007 was started the modernization program of the streets and neighbourhoods of the city Iaşi (Iasi Metropolitan Association, 2009).

Comparison between the two Regions

The Welsh and North East Region of Romania have many differences in their political and administrative structure, economy and technological progress. In terms of low carbon mobility, the United Kingdom, and thus Welsh Region has a long tradition taking into consideration in their decision making processes the sustainable transport principles. The first step towards a sustainable development of the transport system has been taken by the UK Government in 1977, compared to North East Region of Romania which has began to incorporate these principles into their politics from 2002.

The objective of this paper is to benefit from the Welsh experience in order to further promote and implement green transport strategies in the North East Region of Romania and to highlight the good examples practices taken by the two Regions.

Inspired by the significant Welsh experience, Romania decided to encourage the undertaking of important steps in moving towards low carbon mobility by promoting the development of public transport, cycling and walking. In this context, new cycling infrastructure it has been developed in the North East Region of Romania and people have been encouraged to shift their mobility from private cars to public transport.

Further, based on the Welsh experience on promoting regional policies, decision factors have been contacted with some proposals for decision decentralisation, especially for energy policy issues.

Also, for the promotion of green of green mobility stakeholders and companies involved in transport have been encouraged to modernise their rolling stock of vehicles with new ecological hybrid solution for fuels and energy sources.
Low carbon mobility of the transport infrastructure

New developments related to the transport infrastructure towards low carbon mobility are represented by designing and construction of Long Lasting Pavements which have an initial service life of 40 or more years, Sustainable Pavements, a safer, efficient and more environmental friendly version of road structures and Robust Pavements, which are capable to withstand unusual actions without suffering major faults and without losing functionality.

In the United Kingdom there are a large number of roads equipped with durable rigid pavement (1,500 lane-km), the concrete paving industry being represented by Britpave (Britpave, 2015). Another good example of Long-Life Pavements consists in the so-called Heavy Duty Pavements, used for those roads with an increase number of heavy vehicles, as the M25 London Orbital Motorway having 140,000 vehicles/per in each direction or the westbound carriageway of M4 in Wiltshire, with 4,000 heavy goods vehicles in each direction (EAPA, 2015).

Another pillar for improving the sustainability of a city or a region is the construction and integrating in the existing road network of cycling infrastructure, being the first step in promoting modal shift from car to bicycle (the BEST CARBON REDUCING STRATEGY) having significant benefits on the environment as well for personal health.

Following the decision of the Welsh Government taken in March 2009 to declare Cardiff the first Sustainable Travel City from Welsh, the transport infrastructure has been improved in order to integrate an extended cycling infrastructure. This initiative aimed to encourage as many people as possible to use active or sustainable transport for everyday trips (Cardiff Administration, 2015).

New concepts and construction technologies, developed recently, in the frame of Technical University Gheorghe Asachi of Iasi, such as Long Lasting Flexible Pavements (LLFP) (Tanasele, 2012) involving new concepts of pavement structures, will extend the life of asphalt roads from 25 to 50 years, thus contributing to significantly reduced costs and emissions, during the construction and maintenance processes. In similar way, the implementation of the new developments in the field of concrete pavements (Puslau, 2011) such as Long Lasting Rigid Pavement (LLRP), Steel Fibre Reinforced Concrete, Rolling Compacting Concrete (RCC), will have similar impact on reduced costs and emissions.

The design and construction in Romania of durable pavements started with the direct involvement the Strategic Highway Research Program (SHRP, 1994) designed to evaluate the performance of Romanian pavements and to enhance its pavement performance prediction models, being over 30 LTPP test section in the Romanian program, including asphalt and concrete pavements situated in specific rural and urban locations. One of such RO-LTPP sector, considered as a typical Romanian rigid pavement with extended life, its envisaged design life being of 40 to 50 years, is localized on the national road DN 12A – Miercurea Ciuc – Onesti, km. 30+000 – 30+150 and it has been build 25 years ago (Boboc, V. et al, 2002).

Another example of a Long Lasting Pavement constructed in the North East Region of Romania is represented by the sector build on the national road DN 17 Suceava – Vatra Dornei using a sustainable rigid pavement reinforced with steel fibers, recovered from post-consumed tires, as a part of the EU collaborative research project EcoLanes.

Analysis of robustness concept applied to network and road structures, followed by the analysis of the current structure of Romania’s motorway network, with several suggestions for its future development has been also undertaken in our University. Road network of Iaşi County has been evaluated, with practical recommendations to ensure its robustness in case of unforeseen events by applying robust structures on several road sections. After listing the vulnerabilities to which road networks are exposed, a methodology for determining the main motorway routes, applied for the first time in Romania, and also a case scenario of collapse of a bridge in Iaşi county road network have been developed (Cozar, 2013).
Measures for expanding the cycling infrastructure have been taken also in the North East Region of Romania, starting with reinforcing the existing deteriorated structure and initiation of a large construction project for tracks using various technical solutions, fully described in Chapter 4.

**Case study – life cycle assessment of a cycling path from North-East region of Romania**

In order to improve the urban mobility and to promote and stimulate alternative modes of transportation, in the last years, county decision factors had initiated and implemented an extensive project for rehabilitation of transport infrastructure. As a response to the actual environmental and energetic challenges, the project involved the construction and rehabilitation of cycling paths in Iasi County using different engineering approaches. The main objectives of the project are consistent with the SEE MMS Project – Mobility Management Scheme principals, as well with the Kyoto targets for reducing CO$_2$ emissions. The study based on environmental grounds of cycling infrastructure was performed through a Life Cycle Assessment Analysis.

The Case Study deals specifically with cycling infrastructure carried out using various alternatives, namely reinforcing the existing structure with inter lock pavers blocks on a granular material support layer and executing a complete new cycling path having the same transversal slope as the sidewalk (2%). The Life Cycle Assessment Analysis was conducted on the entire built section of 7980 ml long and 1.0 m wide using a CRADLE TO GATE option, presented in the Figure 3.

**Figure 3 – Cradle to Gate Life Cycle Stage (Curran, 2012).**

The Case Study was conducted taking into consideration four constructive alternatives for the cycling infrastructures, Alternative A and B being equipped with Inter Lock Pavers Blocks and Alternative C and D with Asphalt Concrete BA8.

According Alternative A the cycling path is composed by inter lock pavers block laid on a sand setting bed, supported by a relative thin ballast foundation, constructed over the existing structure, as shown in Figure 4.

According Alternative B the cycling path is composed by inter lock pavers block laid on a sand setting bed, supported by a ballast foundation layer and a sand subgrade, as shown in Figure 4.
Alternative C, according Figure 5, refers to a cycling path composed by an asphalt concrete course, laid on a plain concrete C8/10 base, supported by a ballast foundation layer and a subgrade.

For the Alternative D, the asphalt concrete course is laid on cement stabilized ballast base, supported by a ballast foundation and a subgrade, as shown in Figure 5.

The Global Warming Potential expressed in terms of CO$_2$e emissions has been assessed using the GaBi software, the results broken down accordingly with the materials used for the four alternatives considered being presented in Table 1.
Table 1 – *Global Warming Potential associated with the construction of cycling path.*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Material GWP</td>
</tr>
<tr>
<td><strong>Alternative A – Reinforced existing cycling path with interlock pavers blocks</strong></td>
<td>Inter Lock Pavers Block</td>
<td>6.00</td>
<td>936.21</td>
<td>333,141.32</td>
</tr>
<tr>
<td></td>
<td>Sand Setting Bed</td>
<td>5.00</td>
<td>614.00</td>
<td>908.46</td>
</tr>
<tr>
<td></td>
<td>Ballast Foundation</td>
<td>10.00</td>
<td>1,995.00</td>
<td>4,551.03</td>
</tr>
<tr>
<td><strong>Alternative B - Complete new cycling path with interlock pavers blocks</strong></td>
<td>Inter Lock Pavers Block</td>
<td>6.00</td>
<td>936.21</td>
<td>333,141.32</td>
</tr>
<tr>
<td></td>
<td>Sand Setting Bed</td>
<td>5.00</td>
<td>614.00</td>
<td>908.46</td>
</tr>
<tr>
<td></td>
<td>Ballast Foundation</td>
<td>25.00</td>
<td>4,987.50</td>
<td>4,551.03</td>
</tr>
<tr>
<td></td>
<td>Subgrade</td>
<td>7.00</td>
<td>859.70</td>
<td>2,195.05</td>
</tr>
<tr>
<td><strong>Alternative C - Cycling path with asphalt concrete as wearing course and plain concrete base</strong></td>
<td>Asphalt Concrete BA8</td>
<td>3.00</td>
<td>550.00</td>
<td>22,654.46</td>
</tr>
<tr>
<td></td>
<td>Plain concrete base C8/10</td>
<td>10.00</td>
<td>1,835.40</td>
<td>145,866.64</td>
</tr>
<tr>
<td></td>
<td>Ballast Foundation</td>
<td>10.00</td>
<td>1,995.00</td>
<td>4,551.03</td>
</tr>
<tr>
<td><strong>Alternative D - Cycling path with asphalt concrete as wearing course and stabilized ballast base</strong></td>
<td>Asphalt Concrete BA8</td>
<td>3.00</td>
<td>550.00</td>
<td>22,654.46</td>
</tr>
<tr>
<td></td>
<td>Cement stabilized ballast</td>
<td>10.00</td>
<td>2,114.70</td>
<td>112,181.90</td>
</tr>
<tr>
<td></td>
<td>Ballast Foundation</td>
<td>10.00</td>
<td>1,995.00</td>
<td>4,551.03</td>
</tr>
</tbody>
</table>

For Alternative A, the greatest proportion of CO$_2$e corresponds to the production of interlock pavers blocks due to the mixed Portland cement in their composition, the cement having the highest environmental impact from materials used. Thus, to construct the cycling path on the analyzed sector it was necessary to incorporate 327.7 tons of cement in the mix, which led to the release of 294,658.62 kg CO$_2$e in the atmosphere, the equivalent of 81.13% from the total greenhouse gas emissions.
associated with building the cycling infrastructure with pavers supported by the existing structure. Also, the proportion of each constituent material to the total environmental impact is presented in Figure 6. However, reinforcing the existing structure shows positive effects expressed in terms of environmental impact through the use of small amounts of raw materials and energy required extracting them. Furthermore, the quantity of energy and fuels associated with laying and compacting works will decrease since the foundation course is relative thin compared to the foundation layer of a complete new structure.

**Figure 6 – The Global Warming Potential associated with Alternative A – Reinforced existing cycling path with inter lock pavers blocks.**

For Alternative B it has been considered the same type of pavers as the Alternative A, the acquisition and processing of raw materials for inter lock pavers block representing 89.69% (Figure 7) from the total of 371,447.02 kg. CO₂ equivalent associated with the execution of a complete new paving structure. Compared with the first alternative studied, one can notice the increase with 8,252.23 kg CO₂e in the total Global Warming Potential, largely due to the ballast foundation course of 25 cm thickness.

**Figure 7 – The Global Warming Potential associated with Alternative B - Complete new cycling path with inter lock pavers blocks.**

For Alternative C, according with Figure 8, C8/10 Concrete is responsible for 76.11% from the total greenhouse emission, especially due to the cement existing in the mix. Still, the quantity of CO₂e emitted in the atmosphere is relative smaller than the alternatives with pavers, the energy performance increasing in this case with 52% compared with Alternative 2.
Figure 8 – The Global Warming Potential associated with Alternative C - Cycling path with asphalt concrete as wearing course and plain concrete base.

For Alternative D (Figure 9), given that the amount of cement incorporated in the mix was the smallest compared with the other alternatives, the total Global Warming Potential resulted to be 172,997.98 kg CO₂ equivalent, meaning that this option is the most eco efficient, the impact on the environment decreasing with approximately 54% than Alternative B, which has the highest GWP.

Figure 9 – The Global Warming Potential associated with Alternative D - Cycling path with asphalt concrete as wearing course and stabilized ballast base.

General conclusions

• The new technologies emerged in order to reduce the carbon dioxide emissions refer mostly on carbon efficient cars, which uses alternative sources of fuels, as plug-in hybrid cars, electric cars, fuel cell cars, flex-fuel vehicles, smart use of resources, use of public transport (electric buses) and rail transport.

• The best and most efficient strategy for transition towards low carbon mobility is the promotion of modal shift to public transport, walking, cycling and combined mobility, meaning car sharing, car pooling, taxis, etc. A set of personal choices, as car leasing, car sharing instead of owning a car or choosing to use the public transport for long distance travel and cycling, walking for short distance movement and driving more carbon efficient vehicles is also required.

• The Welsh and North East Region of Romania have many differences in their political and administrative structure, economy and technological progress. Inspired by the significant Welsh experience for sustainable transport policies in the decision making processes, Romania decided to encourage to undertake important steps in moving towards low carbon mobility by encouraging the development of public transport, cycling and walking. In this context, we developed in the North East Region of Romania new cycling infrastructure and encouraged the people to shift their mobility from private cars to public transport.

• The Life Cycle Assessment Analysis conducted on four cycling path alternatives using various materials, in order to fulfil the principles for transition toward low carbon mobility it is recommend to promote alternative modes of transportation, especially non-motorized ones through
construction of cycling infrastructure using the least polluting option, Alternative D – Cycling path with asphalt concrete as wearing course and stabilized ballast base. Also, it has been shown that the greatest proportion of CO₂e corresponds to the production of interlock pavers blocks due to the mixed Portland cement in their composition, the cement having the highest environmental impact from materials used.

References


Success factors and barriers for 100% renewable energy-regions

Harry Spiess 1, Vicente Carabias 1, Oliver Montalvo 2, Diego Sanchez 1, Michael Zolliker 2

1) ZHAW Zurich University of Applied Sciences, Institute of Sustainable Development, Switzerland
2) Bachelor Thesis at ZHAW Zurich University of Applied Sciences, School of Engineering, Energy- and Environmental Technologies.

Corresponding author: Harry Spiess, spha@zhaw.ch

Abstract: During the last decade so-called energy-regions have been established all across Europe (cf. for instance Lund, 2007 and Krajacic et al., 2011). The over-all goal of such projects is to restructure the energy supply system in order to make a transition to renewable energies and to increase energy efficiency (Müller 2014). The motivation and intentions of the initiators extend beyond the environmental aspects as much as they vary due to geographical location and diverging demographical and ecological preconditions.

The aim of the presented study is on the one hand to verify the expectations held by initiators of these energy-regions, and on the other hand to examine the transferability of success factors. Therefore, interviews with experts were conducted to explore the individual understanding of a “100% renewable” or “self-sufficient” energy-region. Furthermore, an analysis on barriers and drivers which emerge during the implementation process was made.

As it turned out, conceptions and processes of energy-regions differ widely in certain aspects. For instance, the constituents traffic or embodied energy might be neglected, thus not playing a part in the regional definition of the fully renewable concept. Nonetheless, similarities have also been identified such as intense persuading of different players and difficulties with environmental authorities acting as barriers for most energy-region projects.

The study is based on the analysis and the profile of four energy-regions in Switzerland: Toggenburg, Goms, Knonauer Amt and Zimmerberg. Tischler et al. (2006) introduce a suitable guideline to study and compare different energy regions. Within this framework each community or city reaches the four development stages towards an energy region (Preparation – Development – Implementation – Evaluation) at a different pace. In conclusion, it can be said that the success of energy-regions crucially depends on the perseverance, conviction and engagement of its initiators and promoters.

Keywords: renewable energy regions, success factors, barriers.

Introduction

Whether a bio-energy village, an energy-autonomous community or an energy-region (projects and initiatives often differ in their designated nomenclature), they all display similar characteristics.

The dominant themes centre on regenerative regional energy provision and increased energy efficiency. As other studies have shown (Roberts 2014, 7-12), apart from cleaner energy provision, economic and social factors also play a major role. The increase in regional value added, independence from energy sources from the outside world, or job creation are often associated with energy-regions (Roberts 2014, 7-12).
The aims of this paper entitled 'Success Factors and Barriers for 100% Renewable Energy-Regions' are as follows:

- The concepts of '100% renewable' and 'energy self-sufficiency' will be more closely examined.
- The development and implementation processes on-going in energy-regions will be categorised and compared.
- With reference to specific case studies, the barriers that slow down or directly hinder the development of an energy-region will be identified. Particular emphasis will be placed on whether similar or identical barriers are present within the different energy-regions.

With the help of research literature and interviews with experts, we aim to answer and discuss the following three research questions:

1. How should a '100% renewable-energy-region' be defined?
2. What are the biggest barriers/challenges to creating an energy region?
3. What solutions have energy-regions adopted in a bid to overcome barriers?

The paper is structured in the following way: Section 2 deals with the results drawn from reviewing the literature relative to concept definitions as well as to the model of an ideal development and implementation process within energy-regions. Section 3 describes how the interviews were organised and how the energy regions to be analysed were selected. Section 4 describes the results of the expert interviews, which are then discussed in section 5. Section 6 seeks to identify research shortfalls and issues that may need further examination, and section 7 presents the conclusion.

**Literature review**

**Definition of an Energy-Region**

In Switzerland, an official definition for an 'Energy-Region' does not yet exist (ARE et al. 2012, 27). However, energy-regions can be identified as those regions that are developing a series of energy projects and have several stakeholders interested in supporting such projects on a regional level (Spät 2007, 11). According to Hoppenbrock & Fischer (2012, 4) an energy-region uses its regional potential to produce environmentally compatible and sustainable energy. ARE et al. (2012, 27) maintain that measures to increase energy efficiency are as important as the production of renewable energy itself.

The size of the region is thus dependent upon two factors: the region as a harbour for both energy production potential, and scope of action (Hoppenbrock & Fischer 2012, 5). There must be enough potential to facilitate the production of enough renewable energy to satisfy the regions annual needs. The scope of action aspect covers the geographical extent of the region with which the various stakeholders are then able to identify. This is relevant in order to ensure 'personal responsibility for energy provision'. Spät (2007, 11) perceives a direct link between the size of the region, the number of available stakeholders, its funding potential and its political decision makers.
Swiss regions that fulfil certain criteria (see Energie-Region 2015) can apply to become part of the Swiss Federal Office of Energy's Support Program (BFE). Once on this program, the region has the right to display an official logo and to use the official title of 'Energy-Region'.

**The definition of Energy Self-Sufficiency**

For the definition of a '100% renewable-energy-region' we rely on the concepts of self-sufficiency (Luft, 2012) and energy autarky (cf. Müller et al., 2011) as well as on the opinions of the interviewed experts (cf. section 4.2).

The concept of energy self-sufficiency is directly connected to the implementation and development of renewable energy (McKenna et al. 2014, 241). As this is a relatively recent concept, to date no precise definition exists. The following two studies attempt to get to the heart of the term 'energy self-sufficiency'.

In the study by Müller et al. (2014, 5800-5810), a region can be deemed energy self-sufficient when there is no necessity to import large quantities of energy from other regions. Müller (2014, 5802) admits that it is hardly possible to reach total self-sufficiency, since regions are not insular systems, but 'open' systems between which there is an on-going, mutual exchange of information, materials, people and energy. Energy self-sufficiency as a vision is synonymous with the use of sustainable local energy resources and as such depends upon three basic elements:

1. The use of local energy resources to provide energy rather than importing energy;
2. Decentralised energy systems;
3. Increased energy efficiency.

McKenna et al. (2014, 241-247) also define energy self-sufficiency as 'the principle of using either local or regional energy resources as opposed to importing energy'. The goals set by the energy-region and its stakeholders define the desired level of the region's energy self-sufficiency. To achieve this, McKenna et al. differentiate between 3 forms of self-sufficiency (2014, 242-243):
• General self-sufficiency: There is a significant tendency towards regional decentralisation of energy provision. Self-sufficiency is a 'by product' of decentralised energy provision and is not itself defined as a specific goal.

• 'On-grid' or balance sheet self-sufficiency: The region or community is seen as energy self-sufficient on an annual basis. In order to deal with variations in supply and demand, network structures such as energy storage facilities, electricity and gas networks are necessary.

• Off grid self-sufficiency: The region is completely separated from its neighbours on an energy provision level (island management) and covers its own energy demand by 100%. To be able to achieve this, extensive facilities to store the energy are required.

• 'Off-grid' self-sufficiency is not always the ideal solution. Regional storage facilities, network infrastructures and other costs necessary to achieve such 'self-sufficiency' also have to be taken into consideration. It is often the case that such regions or communities make do with existing local energy sources, implementing energy efficient measures which in turn reduce dependence upon fossil fuels. Such measures also lead to a strengthening of regional economic viability and to job creation in the region (ARE et al. 2012, 31-32).

Portrayal of the development processes within Energy-Regions

Establishing an energy-region can be achieved in different ways. In their book, 'Auf dem Weg zur 100% Region', Tischler et al. (2006) describe an ideal implementation process, as shown in figure 2. They sub-divide the developmental process of energy-regions into 4 phases: I. preparation, II. development, III. implementation and IV. evaluation. The four main milestones to achieving this are: 1) initiating 2) formatting responsible organisation 3) study of potential is completed, and 4) pilot projects are installed (see figure 2).

Method

The contents of this paper are based on both internet research and literature review. However, the essential information is gathered from focussed interviews with initiators from existing energy-regions.

Expert interviews

In view of the distinctly differing situations in which energy-regions find themselves, expert interviews are a suitable method of answering the pre-determined research questions. The main thread of the interview favours a qualitative method of extracting data, which also facilitates spontaneous, additional questions during the interview. Questionnaires relative to expert interviews also take account of internet web pages posted by existing energy-regions.

The four expert interviews were not only fully recorded but also taken down in writing. The recording transcript permitted the faithful rendition of quotes. In an initial phase, the evaluation of the expert interviews enabled us to divide the research questions into themes, providing them with a corresponding nomenclature. In the second phase, the themes were summarised and tabulated.

In the third phase the material was reappraised. The synergy and the differences of opinion expressed by the various experts were then examined. Specific key terms expressed by individual experts were then extracted and compared.

Selection of Energy-Regions

The following criteria were applied for the selection of the energy-regions under investigation:

• Differing geographical locations;
• Both rural and urban locations;
• Differing environmental requirements;
• Differing socio-economic structures (see table 1);
• Differing stages of development within the energy regions.

According to these criteria, the following four Swiss energy-regions were selected:
• Toggenburg, an 'energy valley' in the canton of St. Gallen;
• The Goms energy-region in the canton of Wallis;
• The Knonauer Amt energy-region in the canton of Zurich;
• The Zimmerberg energy-region in the canton of Zurich.

Table 1 - Demographic and economic classification of the energy-regions. Sources: BFS (2012, 2013), EFD (2015).

<table>
<thead>
<tr>
<th></th>
<th>Toggenburg</th>
<th>Goms</th>
<th>Knonauer Amt</th>
<th>Zimmerberg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (Inhabitants)</td>
<td>45’261</td>
<td>49’965</td>
<td>4’569</td>
<td>120’048</td>
</tr>
<tr>
<td>Surface area (km²)</td>
<td>488,8</td>
<td>113,0</td>
<td>585,8</td>
<td>104,3</td>
</tr>
<tr>
<td>Population density (inhabitants per km²)</td>
<td>92,6</td>
<td>442,2</td>
<td>7,8</td>
<td>1’151,0</td>
</tr>
<tr>
<td>Population development (2000-2010) (%)</td>
<td>-4,9 to -2,5</td>
<td>≥ 15,0</td>
<td>≤ -5,0</td>
<td>5,0 to 9,9</td>
</tr>
<tr>
<td>Taxable income (Swiss Francs/inhabitant/year)</td>
<td>51’836</td>
<td>77’976</td>
<td>37’145</td>
<td>89’258</td>
</tr>
<tr>
<td>Employment development (2001-2008) (%)</td>
<td>-1,9 to -0,1</td>
<td>8,0 to 15,9</td>
<td>&lt; -3,9</td>
<td>4,0 to 7,9</td>
</tr>
</tbody>
</table>

The Toggenburg energy valley and the Goms energy-region were chosen because of their geographical locations and because they are already at an advanced developmental stage in terms of energy-regions. The Knonauer Amt energy-region was selected due to its proximity to the Zurich urban area and its already advanced energy policy. The Zimmerberg energy region was of interest to our study because it is just starting out, and being part of greater Zurich area it has a much higher population density level. Thus, the rural regions of Toggenburg and Goms can be compared with the peri-urban region of Knonauer Amt and the urban Zimmerberg region. The decline of both population and jobs in the Toggenburg and Goms regions, as well as the high population density in the Zimmerberg region are strikingly obvious (see Tab. 1).

Results

The responses derived from the expert interviews helped us to answer the research questions quoted in the introduction to this paper.

The definition of an Energy-Region

To understand what constitutes our vision of an energy-region, the two following questions are relevant:

1. What does the definition of a 100% renewable energy-region include?
2. What degree of energy self-sufficiency (according to McKenna et al., 2014) should be aimed for?

Each of the four experts interviewed came up with a different answer to question 1 (see table 2). All four regions demonstrated the will to provide energy from sustainable, local (renewable) sources. This was particularly relevant with regards to electricity and heating supply. Mobility was only included in
the Toggenburg region. Although the other regions did see mobility as an important factor, they felt that it could not really be influenced.

Table 2 - Interviewees differed as to the definition of renewable energy-regions.

<table>
<thead>
<tr>
<th>Definition of “100% renewable”</th>
<th>Toggenburg</th>
<th>Knonauer Amt</th>
<th>Goms</th>
<th>Zimmerberg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity, Thermal energy, Mobility (incl. air travel), Grey energy</td>
<td>Electricity, Thermal energy</td>
<td>Only the general use of local resources is relevant</td>
<td>Electricity, Thermal energy</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 shows which of the three forms of self-sufficiency (taken from Mckenna et al., 2014, 242-243, see 2.2) surfaced during the expert interviews. The Toggenburg and Knonauer Amt energy-regions both strive for ‘on grid/balance sheet’ energy self-sufficiency, so that during the year at least as much energy is produced as is needed. For the Zimmerberg region the term tendency towards general self-sufficiency’ holds true (Mckenna et al., 2014). Hallenbarter (Goms region, 2015) and Mueller et al. (2014) agree that regions should not aim for total off-grid-energy self-sufficiency – an island system – that functions completely independently.

Table 3 - Differing interpretations of the term ‘self-sufficiency,’ according to McKenna et al. (2014).

<table>
<thead>
<tr>
<th>Definition of Self-Sufficiency</th>
<th>Toggenburg</th>
<th>Knonauer Amt</th>
<th>Goms</th>
<th>Zimmerberg</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Grid/Balance sheet</td>
<td>On Grid/Balance sheet</td>
<td>no declaration</td>
<td>Tendency towards general self-sufficiency</td>
<td></td>
</tr>
</tbody>
</table>

Barriers and challenges to establishing an Energy-Region

The results from the expert interviews show that in the four regions under examination, collaboration between the various stakeholders involved was, in most cases, highly successful. Stakeholders who failed to get involved (apart from community representatives) were not perceived as a barrier. None of the stakeholders were against creating an energy-region. Egoism, opposition and high administrative costs were thus not mentioned as risk factors.

From the barriers listed in table 4 several common points of agreement clearly emerge. In Toggenburg, Knonauer Amt and Goms the major challenge is to convince people that investment in renewable energy is worthwhile. This is a challenge because people are not really interested in the topic, plus the fact that financial investment is required for which there is little available funding. Another important aspect is that building projects (renewable energy plants such as wind farms or solar installations), which need authorisation, frequently fail because of conditions laid down in landscape, nature or environmental laws. Especially in the sparsely populated Toggenburg and Goms regions, the withdrawal of committed employees could compromise the continuity of energy projects. The Zimmerberg energy-region was the only one to perceive low development potential for renewable energy as a barrier.
Table 4 - Barriers to the creation of energy-regions.

<table>
<thead>
<tr>
<th>Barriers and Challenges</th>
<th>Toggen-burg</th>
<th>Knonauer Amt</th>
<th>Goms</th>
<th>Zimmer-berg</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Economic viability of energy production plants</td>
<td>X</td>
<td>XX</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>• Lack of demonstration of the additional benefits and savings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Long pay-back period of renewable energy installations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Absence of human resources</td>
<td>XX</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>• 'Unsuitable' people for a project</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Committed stakeholders cannot be tied down for the long term</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Energy issues are not uppermost in peoples’ minds</td>
<td>X</td>
<td>XX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Low demand, although supply is present</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Short term thinking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Low level of acceptance among the population</td>
<td>XX</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Lack of approval for the energy projects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Single projects cannot be implemented</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Failed projects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Low energy prices</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• High costs</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• Lack of financial resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Landscape and nature protection</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• Protection laws for home and countryside</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Politically conditioned founder groups</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>• Local authorities show no interest</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>• Few resources (e.g woodland) and therefore low development potential</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>• Lack of - or inadequate organisational form</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

What solutions have energy-regions adopted in order to overcome barriers?

An important criterion to creating a successful energy-region is the political will of each community to play an active role within the energy-region. This establishes the basis for successful collaboration beyond community boundaries, and helps to 'boost start' the implementation of projects (see 2.3). Political will gives legitimacy to the creation of renewable energy initiatives, and justifies the provision of both personnel and financial means (Müller 2014, 243). Only people who are very committed and convinced of its necessity can manage an energy-region. Such people are mostly voluntary. They are tireless in their efforts to convince both population and stakeholders alike as to the desirability of energy-regions.
Table 5 - Solutions for successful energy-regions.

<table>
<thead>
<tr>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Toggenburg</strong></td>
</tr>
<tr>
<td>• Each community in the region is included</td>
</tr>
<tr>
<td>• Transparency and raising awareness</td>
</tr>
<tr>
<td>• Strive for dialogue with critics</td>
</tr>
<tr>
<td>• Personnel is capital</td>
</tr>
<tr>
<td>• Persistence, patience</td>
</tr>
<tr>
<td>• Professional management</td>
</tr>
<tr>
<td><strong>Knonauer Amt</strong></td>
</tr>
<tr>
<td>• Savings due to collaborative action</td>
</tr>
<tr>
<td>• Readiness to tackle tasks together</td>
</tr>
<tr>
<td>• Solidarity within the region</td>
</tr>
<tr>
<td>• Successes experienced</td>
</tr>
<tr>
<td>• Benefit production</td>
</tr>
<tr>
<td>• Sponsoring</td>
</tr>
<tr>
<td><strong>Goms</strong></td>
</tr>
<tr>
<td>• Committed personalities</td>
</tr>
<tr>
<td>• Persistence</td>
</tr>
<tr>
<td>• Presence</td>
</tr>
<tr>
<td>• Project transparency</td>
</tr>
<tr>
<td>• Raising awareness</td>
</tr>
<tr>
<td>• Persuasion</td>
</tr>
<tr>
<td>• Value creation compensating weak local economy</td>
</tr>
<tr>
<td><strong>Zimmerberg</strong></td>
</tr>
<tr>
<td>• A healthy financial situation in the communities</td>
</tr>
<tr>
<td>• Projects that have been successfully implemented</td>
</tr>
</tbody>
</table>

To succeed, an energy-region depends on committed public relations initiatives and raising awareness among all the stakeholders concerned. Absent stakeholders or critics have to be convinced through dialogue about the use of projects. Transparency of communication together with a great deal of patience and persistence have contributed to Toggenburg’s progress as an energy-region. Another contributory factor is that Toggenburg has created a special office, and rewarded some employees. Committed people, whether paid or voluntary, provide an important basis for a successful energy-region (Grob, 2015).

To sum up, three main points clearly emerge from the listed solutions (table 5):

1. Wide consensus among all the communities in the region and willingness to cooperate;
2. Committed, motivated and persistent people as promoters;
3. Raising awareness through constructive, transparent communication, and public relations.

**Discussion**

The energy-regions examined in this paper differ from each other in size, geographical situation and economic capacity (see table 1). In addition, each region is at a different stage of development relative to its installation as an energy-region. The most interesting aspect is revealed by the comparison between rural (Toggenburg, Goms) and peri-urban/urban (Knonauer Amt, Zimmerberg) areas.

**Rural regions**

Due to their earlier start as energy-regions, rural regions like Toggenburg and Goms have already gathered a lot of experience. However, they have also suffered setbacks with some projects, and their Development Association has already had to cope with employee changes. They are therefore of the opinion that it is important to motivate promoters and other stakeholders. Both rural regions have a low population density and suffer from the decline of both population and jobs (see Table 1). This is
in line with the statement of Roberts (2014, 57), that the main motivation for creating an energy-region lies in its economic situation. Exploiting renewable energy and the value it adds at a local level will ultimately create new jobs in the region (ARE et al. 2012, 3) resulting in the rise of employment levels.

Periurban and urban regions

Urban regions like Knonauer Amt and Zimmerberg have a much higher population density. They started out later as energy-regions and were financially much better off (see table 1). A healthier economic situation opens the door to better opportunities, and potential can be exploited more efficiently. Communities can afford to take part in both individual projects and development associations. However, in urban regions with a high population density it is doubtful that energy needs can be covered 100%, because the potential for renewable energy sources is lacking. It is not possible to judge whether acceptance of energy projects is higher or lower amongst the urban population than it is in rural regions, or whether political processes are faster or slower.

Comparison of the developmental processes within the Energy Regions

When comparing the energy-regions as shown via the road maps in figure 2, various similarities and differences in implementation come to light. Toggenburg and Goms were amongst the first energy-regions in Switzerland to get started. Both regions acted as inspiration to other regions such as Knonauer Amt (Höhn, 2015) and Zimmerberg (Porro, 2015). The developmental processes were, however – taking into account the current differing frameworks – very different (see figure 2):

1. The road from initiation to implementation were of varying speeds
2. Milestones, such as 'potential studies' were achieved in different phases and in a different order.

Linking barriers and solutions

In this part, with the help of some of the important barriers that energy-regions come up against, we aim to show the solutions that have helped the regions under examination to overcome them (see table 6).

As the results show, convincing people within the communities is not always an easy task. Sometimes a community's legislative goals are not always compatible with the 'vision' of energy-regions. In an attempt to meet and solve this challenge, Tischler et al. (2006, 46) state that it is vital to extend the parameters of the core group and supporters via additional key stakeholders. Such people should be well connected and rooted in the region. This increases credibility and the possibility of winning over the more skeptical stakeholders by force of reasoned argument.

The low level of acceptance and the lack of interest displayed by the population towards energy matters is one of the biggest challenges facing energy-regions. This can be resolved by taking specific, suitable measures such as the dissemination of information, installation visits, excursions and inauguration celebrations. The media can also make a useful contribution to promoting acceptance by publishing positive articles on the subject of energy-region development. Raising awareness amongst children and young people via workshops or project weeks in schools are initiatives of a more long term nature. It is nevertheless important to make the younger generation aware of the energy problems we face both today and tomorrow.
Figure 2 - Ideal Road Map according to Tischler et al. (2006) and comparison of the road maps between the 4 regions.
### Table 6 - Barriers with their corresponding solutions.

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>The difficulties facing communities and administrations</td>
<td>Promoters who care and key stakeholders to convince the population</td>
</tr>
<tr>
<td>Low acceptance among the population</td>
<td>Raising awareness and public relations</td>
</tr>
<tr>
<td>Landscape and nature protection laws hinder projects</td>
<td>Making contact in good time and clarifying legal frameworks</td>
</tr>
<tr>
<td>Political parties in energy-regions</td>
<td>Establishing development associations</td>
</tr>
<tr>
<td>Making appointments with very busy stakeholders</td>
<td>Persistence and patience</td>
</tr>
</tbody>
</table>

Projects such as wind farms or solar installations frequently fail because of landscape, nature or environmental laws. Nature and environmental protection bodies make justified objections to wind, solar or hydro-electric projects. It is therefore necessary to establish a constructive dialogue and collaboration with authorities from the outset of a project. This task can be undertaken by a Development Association, acting as an arbitrator between authorities and project leaders.

The very nature of party political grouping means that their message will not reach the entire population. It is therefore advisable to form neutral development associations able to communicate with all the stakeholders. This will hinder individual parties seeking to gain an advantage by vote catching prior to elections.

Awareness of the fact that the development and implementation of an energy-region is a long term process that requires patience and tenacity is essential. These two virtues are indispensable to promoters. Setting up appointments with stakeholders can be tedious and long drawn out, which in turn can delay the development of an energy-region. As Grob (2015) aptly observes, it is “a constantly back breaking task and in no way a foregone conclusion”.

**Success factors**

By examining three Swiss energy-regions together with one from Austria and one from Germany, ARE et al. (2012, 76-78) have identified the following success factors in the creation and management of energy-regions:

1. **Context**: energy prices, costs of renewable energy, promotion by the State.
2. **Stakeholders**: promoters and investors are especially important as is cooperation between all the stakeholders.
3. **Input factors**: Availability of sufficient natural energy-resources within the region, suitable locations for energy production, capital under favourable conditions, know-how.
4. **Development process**: Vision and goals, organisational structures, lighthouse projects, communication and raising awareness, knowledge creation and linking.

In point 1, by context we refer to exogenous factors which are established either nationally or internationally and over which regions have little influence. Based on our expert interviews it becomes clear that the success factors 2 and 4 mentioned above, in all the cases we examined with differing start up situations and frameworks, merit particular attention. Likewise, the initiators of the energy-regions, the so called ‘promoters’ have been the vital backbone for all the successful regions. Their tireless and mainly voluntary involvement has been an invaluable driving force for the energy-regions. Having a firm base in their locality means they are highly motivated and committed to the cause of pushing projects through for the benefit of the region. Such ‘promoters’ are vital key factors in the
establishment and progress of energy-regions, and without their ceaseless efforts, progress in this
direction would scarcely be possible.

Our interviews also reveal that a far reaching consensus of opinion between all the stakeholders is
also necessary. This can be achieved by raising awareness and public relation exercises, this is,
however, a slow and steady longer term process. Each region tackles these challenges in differing and
very individual ways. In some German regions, for example, renewable energy is on the increase with
a higher level of acceptance, fuelled by active citizen participation and cooperatives (Ott & Wieg 2014,
829 - 841). Only when every community in the region is convinced by the efforts of promoters and
initiators to embrace the creation of an energy-region, can the structure take form. This is important
in order to include the goals and strategies expressed by each individual community in the overall
picture.

Müller (2014, 243) argues that political will acts as a 'signal' to the communities, providing a legal
framework which empowers them to make financial investments and create employment
opportunities. However, it would seem that an important element in this process is the presence of a
non-party political organisation, e.g. a Development Association. Such an organisation helps to
increase acceptance among the stakeholders, especially among potential investors and within the
population as a whole. Spät (2007, 47-50) sees success factors as the correct order of the regions
based on size, community-wide structures and opportunities to access regional funding programs.

While attention to general principals of innovation can improve policy-making, sensitivity to a broad
range of contextual variables is likely to be more important in the domain of renewable energy
innovation policy than in conventional innovation policy-making according to IRENA (2013). Therefore,
in the attempt to endorse the results of this study to other countries, the Swiss particularities (e.g.
high standard of living, increasing comfort in buildings, reliable energy supply security, non-fossil
power mix, democracy and participation in decision-making) have to be taken into account.

Critique of methodology

The use of international studies is limited in relation to the Swiss context. In the national literature
review as well as in the expert interviews presented in the sections above, responses seemed to be
biased resulting in purposive optimism expressed by overeager and engaged authors and experts, as
they faded out not only the grey energy but also the energy consumption of transportation in contrary
to the international references (e.g. Lund et al., 2011).

Outlook

As a relatively new phenomenon, energy-regions provide an ideal breeding ground for future
research. Below we have highlighted some possible issues that may be useful in helping energy-
regions to continue to evolve in the future.

• What values can actually be generated within the region? How can they be measured?

• Does energy self-sufficiency make good sense in view of globalisation and networking? If it does,
how can energy self-sufficiency be intelligently defined?

• What lessons can be learned from those energy-regions or communities that have failed?

• What role do new or existing labels such as 'energy-city', or 'energy-region' play in the quest to
become an energy-region?

• How can the Federal Government, likewise the Swiss Federal Agency of Energy develop energy
support programs? How can the next steps/phases be tackled?
Conclusion

In conclusion, we can say that the answers derived from the interviews we carried out mirror the situation relative to the diversity of the different energy-regions. In Switzerland, energy-regions are a new phenomenon. As it turned out, conceptions and processes of energy-regions differ widely in certain aspects. For instance, the constituents’ traffic or embodied energy might be neglected, thus playing no part in the regional definition of the fully renewable concept. Nonetheless, similarities have also been identified such as the intense persuasion of different players, and the difficulties with environmental authorities acting as barriers for most energy-region projects.

With committed promoters leading the way, energy-regions can be changed in the long run. It is a long and hard process which can only happen thanks to the support and determination of all the stakeholders involved. It is therefore necessary to ensure that both initiators and development associations are allowed the freedom to structure the processes they consider best suited to the task. We can see that the implementation process takes account of local circumstances, for which reason it is necessary to permit individual solutions. When establishing frameworks, the Federal government has to support the work at a local level and recognise the work done by development associations without exerting too much 'top down' pressure.

Acknowledgements

This work resulted thanks to the participation of experts and the research project C13.0147 Towards Smart Energy Regions funded by the Swiss State Secretariat for Education, Research and Innovation (SERI).

References


Grob, Thomas (Interview 13.04.2015).

Hallenbarter, Dionys (Interview 14.04.2015)

Höhn, Charles (Interview 14.04.2015)


Porro, Tom (Interview 14.04.2015)


Tischler M et al. (2006): Auf dem Weg zur 100% REGION. München: B.A.U.M. Consult GmbH
Energy modelling of regions using stakeholder generated visions as scenarios

Simon Lannon, Heledd Iorwerth, Malcolm Eames, Miriam Hunt

Welsh School of Architecture, Cardiff University, Wales UK. Corresponding author: Simon Lannon, lannon@cardiff.ac.uk

Abstract: To achieve the UK Government Carbon Emissions targets, large scale retrofitting of the built environment is required. This paper will explore the changes required to achieve the retrofitting targets for dwellings based on visions of the character of the Cardiff City region in 2050. The three visions of a utopian future: i) Connected Cardiff; ii) Compact Cardiff–Wilderness Valleys; iii) Orchard Cardiff City-Region represent scenarios with different societal and land use changes. They all achieve the 80% reductions required, but have different pathways to this goal.

Building on earlier work based on “Bottom Up” urban scale model EEP, this paper will outline the modelling of large areas using extensive data sources that describe the existing stock. Together with the scenario work, this research models societal changes represented by population and household size change and the associated energy use. The paper discusses data sources required and methods to model population and household changes.

The results generated from the model show the retrofit pathways required to achieve the targets set. In addition the outcomes of the research are visualised through mapping of the pathways across the Cardiff City region.

Introduction

The UK government has set an ambitious target of 80% reduction of Carbon emissions by the year 2050. As the vast majority of buildings that will exist in 2050 have already been built, and the interactions of the Carbon emission reduction methods, such as fabric improvements, occupant behaviour and renewable technologies in the urban retrofit design process need to be researched further.

The Welsh Government have committed to achieving annual emissions reductions of 3% Carbon equivalents in areas within their competence (WAG, 2010a). In addition, power generation emissions are also included in the 3% target, by assigning them to the end-users. This is in recognition of the importance of reducing electricity consumption as part of achieving sustainability goals. Taking the above into account, the residential sector becomes a key target area for reductions as it represent 30% of the emissions within Welsh Government competence (WAG, 2008) and the aspiration has been expressed to make all new buildings “zero Carbon” in future. Other goals include reducing the use of Carbon-based energy by 80-90%, and at least matching electricity consumption in Wales with power generated from renewable sources by 2025 (WAG, 2009) which would translate to more than 30TWh of renewable electricity and 3TWh of renewable heat per year.

More ambitious views have also been expressed, which involve generating twice as much renewable electricity in 2025 as presently consumed in Wales, and covering all local energy needs by low Carbon electricity by 2050 (WAG, 2010b). In this context, local authorities in Wales share the responsibility of improving and maintaining building stock condition to certain levels of sustainability (NAW, 2001), and
promoting the deployment of renewable energy schemes in their area (WAG, 2010c). The Welsh residential sector has a larger share of hard to treat properties compared to the rest of the UK. This could mean higher potential for energy efficiency improvements but also higher associated marginal costs (Baker and Preston, 2006). There is currently no representative residential stock model for Wales, and studies quoted in literature model the region based on data from other parts of the UK (Hinnels et al., 2007). In view of the policy targets and stakeholder responsibilities at the local authority level, it is necessary to obtain a more accurate portrayal of the sector in order to address stock-specific constraints and opportunities in Wales. Recent research has used a top-down model to derive insights on the impact of retrofit measures at local authority level (Gandhi et al., 2012). Focusing within the local authority at a lower level, this bottom-up approach goes one step further to demonstrate the possibility of providing policy makers and stakeholders at the local level with valuable information on the potential for retrofit based on area specific data.

**Cardiff City Region**

The concept of a Cardiff or South East Wales city region was a rather vague one without a clear geographic or administrative boundary, or governance structure. For the purposes of this paper a broad view of the city-region was taken including the local authorities of Neath Port Talbot and Swansea to the west. This was intended to capture the strong economic connections between the three urban regions along the south coast (Newport, Cardiff and Swansea) which differ significantly from the neighbouring rural regions of West and Mid Wales. More recently the Welsh government has announced the creation of separate City Region Boards for Cardiff South East Wales and Swansea Bay.

The Cardiff City Region, as defined for the purposes of this paper, is home to some 1.86 million people. That is 60% of Wales’ population despite spanning only 17% of its area. Indeed, the three urban centres of Swansea, Cardiff and Newport account for 24% of the Welsh population. Population density varies across the project area, with Cardiff by far the most concentrated.

The region has been divided by Welsh Government into four zones which cross the local authority boundaries, Head of the Valleys, Connections Corridor, Cardiff Coastal Zone, and Swansea Coastal Zone (figure 1). These zones have been used in the visioning to express the population movement of the City region from 2014 to 2050.
Visioning process

The Retrofit 2050 project created three contrasting long term (2050) visions for retrofit city-regional futures, developed through an extensive research process that spanned 2011-2013, including: a series of workshops that brought together national experts in the fields of water, waste, energy and transport. These contextual scenarios were intended as a tool which can be adapted and used by a wide variety of stakeholders and organisations to stimulate discussion and inform future policy and long-term planning (Eames 2014).

The three visions each describe distinctive long-term visions of what a sustainable future might look like for core UK city regions in 2050. The three visions are:

- **Smart-Networked City**: envisages the city as a hub within a highly mobile and competitive globally networked society.
- **Compact City**: envisages the city as a site of intensive and efficient urban living.
- **Self Reliant-Green City**: envisages the city as a self-reliant bio-region, living in harmony with nature.

Each of these futures is described by two key dimensions of change for systemic urban retrofitting: change in land-use and urban form; social values and institutions.

Regional visions

The national visions were then grounded in the Cardiff city region by the Retrofit 2050 project team using workshops incorporating regional stakeholders from local government, industry and civil society groups, semi-structured interviews with regional stakeholders and a desk-based review of relevant policy documents and grey literature.

The Cardiff 2050 City Regional Scenarios therefore represent an exploration of how these different articulations of urban sustainability can be manifest and grounded in the economic, political, social, technological and ecological transformation processes shaping the development of Cardiff and South
East Wales. The narrative for each of the Cardiff scenarios is built upon a ‘pitch’ developed by the participants during the regional workshop, intended to summarise Cardiff’s bid for the prize of ‘best retrofit city’ in a fictional future ‘European Sustainable Cities of 2050’ competition. The very different assumptions about future population and settlement patterns embodied in the scenarios also reflect the divergent views of the expert participants in the regional workshop.

The modelling of these visions explores the change in population and household size to develop a stock profile of the Cardiff City region in 2050 (Table 1). This profile has been modelled to guide policy makers to the extent of the retrofitting required to achieve the UK Government 2050 emission reduction targets.

**Table 1 - Scenarios Summary and Indicative Indicators.**

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Connected Cardiff</th>
<th>Compact Cardiff - Wilderness Valleys</th>
<th>Orchard Cardiff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicative population and population changes (2050)</td>
<td>2.75 million&lt;br&gt;High population growth Inward migration</td>
<td>2.25 million&lt;br&gt;Moderate population growth Internal redistribution</td>
<td>1.75 million&lt;br&gt;Moderate population decline Outward migration</td>
</tr>
<tr>
<td>Household size (2050) persons per house</td>
<td>1.95 Business as usual&lt;br&gt;trend</td>
<td>2.32&lt;br&gt;City centre living</td>
<td>2.60&lt;br&gt;Return to 1970 household sizes</td>
</tr>
<tr>
<td>Change in building stock composition (2014-2050)</td>
<td>640,000 New build&lt;br&gt;770,000 Retrofitted&lt;br&gt;30,000 Demolished</td>
<td>310,000 New build&lt;br&gt;660,000 Retrofitted&lt;br&gt;140,000 Demolished</td>
<td>60,000 New build&lt;br&gt;610,000 Retrofitted&lt;br&gt;190,000 Demolished</td>
</tr>
</tbody>
</table>

**Cardiff city-region stock**

The Cardiff City Region, as defined for the purpose of this chapter, consists of 12 Welsh Local Authorities. Within this region, nestled along the south coast, are Wales’ 3 major urban areas (Newport, Cardiff and Swansea) which account for 24% of the Welsh population. Inland from these urban areas is the South Wales coal field and the communities that evolved due to the industrial revolution. The region therefore consists of densely populated valleys and coastal cities as well sparser areas such as those found in the Vale of Glamorgan and Monmouthshire which have remained largely rural in nature. The Office for National Statistics’ hierarchical system builds up from clusters of adjacent postcodes into areas of a similar number of households (Output areas) forming a logical geographical base for analysing the housing stock.

A region’s housing stock is a consequence of its past: of the techniques used when built and the major and minor modifications made through the years. Subtle and dramatic variations can be observed both between and within areas. Understanding and representing these variations is key to modelling the energy consumption of dwellings at a regional scale.

When compared to the UK housing stock, Cardiff City Region’s stock contains a substantially larger proportion of pre 1919 terraced houses with a relatively low proportion of new builds (Figure 2). In order to model future visions, the region’s stock must be analysed on smaller geographical levels, allowing the representation of current and potential economic and social situations.
Modelling at an urban scale

Modelling the energy consumption of domestic buildings at an urban or regional scale has traditionally been undertaken in a top-down policy orientated way, where the gross energy consumption data provided by the energy suppliers is used as a starting point (Swan and Ugursal 2009). This data is then analysed using stock surveys to give average composite buildings that can be analysed (Gouldson et al. 2012) using building modelling techniques. This top-down approach is reliant on historical data to produce predictions, rather than based on building physics modelling. This method has inherent difficulty in dealing with new technologies and changes in occupant behaviour and their likely impact on future energy consumption.

Alternatively bottom-up approaches have the potential to model buildings in great detail to take into account complex interactions of building occupants, passive design and active systems. Initial attempts to model at the urban scale through a bottom-up modelling approach such as the Energy and Environment Prediction model (EEP) (Jones, et al. 2007) are based on steady state models, such as the Standard Assessment Procedure (SAP) (BRE 1998). They predict the energy consumption for archetypes of buildings that represent the considered building stock. In a recent review (Sanaieian et al. 2014), EEP was still considered one of the primary methods for modelling energy performance of buildings at an urban scale. Kavgic et al. (2010) described the model as an exemplar and base their work firmly on its achievements.

EEP model

The EEP model simplifies the simulation of the urban environment by using simple standard energy prediction tools, and ways of grouping houses together. The grouping of houses usually follows the type of house e.g. terraced, semi-detached or detached, which is reasonable for simple problems, but when trying to predict the energy use of a detached house it could be two ends of a very large scale, from a labourers cottage to a mansion. The logical way to further group houses is by their size and...
when they were built. To do this a number of common house types are surveyed, and the results of these surveys are clustered together to give groups of houses with similar energy predictions.

The EEP model uses the UK government’s Standard Assessment Procedure (SAP) (BRE, 1998) as the method for measuring the Carbon emissions related to residential building stock. The model within EEP has been adapted to allow the modelling of fabric retrofit, building integrated renewable technologies and occupant behaviour. The EEP model allows for “what if” functions to target different retrofit options, and this capability has been developed further using the population and household size predictions from the ONS and stakeholder derived visions for 2050 allowing the domestic energy demand for a small census area to be tracked through time.

Data sources
As large numbers of dwellings are considered when studying a city or region, it is important that the information about each dwelling is easily collected and modelled. A number of datasets were investigated including Valuation Office Agency data which has a complete breakdown of property types down to LSOA level, and the UK Map dataset which is a GIS based classification of building blocks – age, typology, floor area and building heights. These building based datasets were compared to the Census which has a wide range of single or bivariate data on LSOA or OA level. Finally, energy efficiency measure installation data is required to predict the energy performance of buildings. The Energy Saving Trust’s Home Energy Efficiency Database (HEED) which contains records of energy efficiency installations grouped by local authority, age and typology and DECC’s NEED database which is a weighted sample of properties on a regional level were used.

From these datasets a procedure was developed for use within the model that groups together dwellings with similar energy performance characteristics creating ‘house types’. This needs fewer calculations when the whole or large sectors of the local authority are investigated. For example, if all houses within an area can be reduced to 240 types based on built age, typology and size, then subsequent calculations only have to deal with 240 house types and not every house in the area. This allows real time calculations to be carried out, such as estimating the consequences of applying specific energy saving measures.

A cluster analysis technique, similar to the EEP model, was used to identify dwellings with similar energy consumption and Carbon dioxide emissions. The characteristics chosen for the clustering are considered to have the greatest influence on domestic energy performance (Table 2).

City region scenario modelling
Three visions of urban sustainability: a ‘smart’ city future, a ‘compact’ and a self-reliant green’ city regional future, have been used as the basis for a regional building stock model. The order of modelling does not follow chronologically but rather follows the order described by the numbering in figure 3: (1) 2014/15 -> (2) 1990 -> (3a, 3b, 3c) 2050-> (4ai, 4bi, 4ci ...) 2015 to 2050. This stock model starts from the baseline of 2014/15 and moves backwards to 1990. The 1990 model is to be used to measure the visions’ ability to reach the 80% reduction in Carbon emissions by 2050 compared to 1990. The model will then attempt to represent the region in 2050 according to the three visions. Pathways to reach the 2050 visions will then be modelled in steps of five years from 2015 to 2050.
The baseline model is based on the Valuation Office Agency’s (VOA) 2014 database of the UK’s current housing stock per LSOA. The data gives the number of each property type in each LSOA and distinguishes properties as shown in Table 2.

Table 2 - Property Types – Age, Typology and Size.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Typology</td>
<td>one of 5 typologies</td>
<td>Bungalow, Detached, Flat/maisonette, Terraced, Semi,</td>
</tr>
<tr>
<td>Size</td>
<td>number of bedrooms</td>
<td>1, 2, 3, 4+,</td>
</tr>
</tbody>
</table>

This gives 240 types of property types allowing detailed modelling of the building stock to be undertaken.

Number of dwellings - 1990
The number of dwellings in the 1990 model per LSOA was based on the number of dwellings built before 1993 in the VOA database.

Number of dwellings – 2050 Scenarios
The 2050 scenarios developed for the region outlines the approximate number of dwellings built and demolished by the year 2050. Within the narratives of these visions, conditions for the demolition and building of new dwellings were derived:

Connected Cardiff:
- New build in peri-urban – Large Increase;
- New build in less dense urban – Large Increase;
- Expanding housing supply;
- 30,000 dwellings demolished (4%);
- 640,000 new build.

Compact Cardiff - Wilderness Valleys:
• New build in less dense urban – Moderate Increase;
• A lot of the valleys towns uninhabited, uplands demolished, more wild sparse hinterland;
• Growth of medium to high density urban conurbations;
• High density neighbourhood centres within/around Swansea, Bridgend, Cardiff, Newport;
• 140,000 dwellings demolished (17%);
• 310,000 new build.

Orchard Cardiff:

• Demolition of poor dense stock – Moderate decrease;
• Demolition urban/peri-urban;
• 190,000 demolished (24%);
• 60,000 new build.

These conditions can be modelled on LSOA levels using the four geographical indicators rurality (figure 4), flood risk (figure 5), regional zone (figure 1) and density as a percentage of built upon land. Some of the vision data cannot be modelled as it would be required to identify geographical areas within LSOAs. As the model is based on LSOA level data, these conditions are not modelled for the demolition and new build in the compact vision. In spite of this, it is hoped that the modelled scenarios using the above indicators can represent the three visions of urban sustainability reasonably accurately.

Figure 4 - LSOA rurality (Office for National Statistics 2011).
**Results from modelling**

The outcome of the modelling process allows the Cardiff city region to be modelled from 1990 to 2050. The population and household size projections for the three visions are very different and the modelling of these considering the data at a LSOA level shows the different pathways to the visions in 2050. In the maps of number of households (figures 6 to 9) the existing levels show a reasonable consistent level of building density throughout the region (Figure 6). The Connected Cardiff vision takes advantage of the lower valleys’ connected corridor as a resource for increasing housing, building on the proposed Metro and a shift towards the use of public transport to deliver future development of the economy. This is shown with an increased urbanisation of the corridor highlighted by the dark red LSOAs on the map (Figure 7). The Compact Cardiff vision deals with flood risks through flood defences based upon tidal lagoons and barrages and shows massive densification of housing (darker southern LSOAs) in the coastal zone of the city region. In addition the re-wilderness of the upper valleys lead by the demolition of hard to treat housing is shown by the lighter shades towards the north and the Heads of the Valleys zone (Figure 8). The Orchard Cardiff vision expresses the greening of the city centres (lighter shades) and the increase use of a Metro system to provide access to land throughout the city region (Figure 9).
Figure 6 - Existing households per LSOA.

Figure 7 - Households per LSOA for Retrofit 2050 Connected Cardiff Vision.
Figure 8 - Households per LSOA for Retrofit 2050 Compact Cardiff Vision.

Figure 9 - Households per LSOA for Retrofit 2050 Orchard Cardiff Vision.
Proceedings of the International Conference ‘Smart Energy Regions’
Cardiff, UK, 11th and 12th February 2016

Figure 10 - Overall progress to the 80% target reduction in carbon emissions.

When the region is considered as a whole the vision process is based on the premise that Carbon emissions will be reduced by 80%. Using the modelling that has been undertaken it can be seen that there has been a 5.5% reduction in emissions in the 24 years from 1990 to 2014 (Figure 10). This leaves the remaining 74.5% reduction to take place over the next 36 years. In terms of annual reduction from 1990 to 2014 there has been a 0.2% annual reduction, the next 36 years will need an annual reduction of 2%.

Conclusions

The paper has shown that it is possible to build a “Bottom Up” urban scale model to describe the modelling of large areas using extensive data sources of the existing stock. This model has been merged with a scenario work based on City Regional visions of a future that achieves the 80% target. The model includes societal changes represented by population and household size change together with geographical indicators such as rurality (figure 4), flood risk (figure 5), regional zone (figure 1) and density as a percentage of built upon land. The sources of the data required are becoming more available and complete and as such give more confidence in model outcomes. The methods of modelling population and household changes are generally applied at a Local Authority level, in this model these are combined with housing data (VOA data) and the migration and stock levels gained from the visions.

The results generated from the model show the retrofit pathways required to achieve the targets set. In addition the outcomes of the research are visualised through mapping of the pathways across the Cardiff City region.

References


Session 3: Energy retrofitting of the built environment
The impact of UK Government policy instruments on quality in domestic solid wall insulation retrofit projects

Tim Forman \textsuperscript{1}, Chris Tweed \textsuperscript{2}

\textsuperscript{1} Centre for Sustainable Development, University of Cambridge, England UK
\textsuperscript{2} Welsh School of Architecture, Cardiff University, Wales UK

Corresponding author: Tim Forman, tim.forman@eng.cam.ac.uk

Abstract: Space heating in domestic buildings accounts for roughly one-fifth of UK greenhouse gas emissions. There are approximately 11 million homes in the UK potentially suitable for solid wall insulation (including hard to treat cavity constructions). Remarkably, an estimated 96 per cent of homes built with solid walls have no wall insulation. Retrofitting these homes with insulation offers the potential to significantly reduce national greenhouse gas emissions while reducing expenditure on fuel, improving thermal comfort and realising numerous important associated benefits. This research began at the onset of an upsurge in national rates of solid wall insulation retrofit in 2011-2012. At that time, anecdotal reports pointed toward a legacy of poor practices and continued problems in the retrofit industry.

Participant and non-participant observation, site inspection and qualitative study were employed in area-based retrofit projects and across a variety of related settings. Analysis outlines ways in which policy instruments have failed to support improvement of practices in the retrofit industry.

The research suggests that unintended consequences are likely to result from many observed practices and it identifies a need to align policy with industry and industry training.

Introduction

Solid wall insulation (SWI) refers to insulation applied to the internal or external face of a solid (or ‘hard-to-treat’ cavity) wall. This paper reports research conducted between 2012 and 2014, at the beginning of rapid growth in SWI retrofitting in UK homes.

Anecdotal reports of poor practices in the SWI retrofit installation industry have long been voiced by many experts. Researchers understand that inconsistency with best practice presents significant risks of unintended consequences, including loss of performance, damage to fabric and impacts on human health and comfort.

A considerable body of evidence in the context of general UK construction practice indicates that energy performance gaps are widespread (Zero Carbon Hub 2014). This work introduces new evidence in the context of SWI and offers explanations of contributing factors.

Context

The UK’s housing stock is among the oldest and least energy efficient in Europe. Of its 27 million homes, 96 per cent of the 7.8 million homes built of solid wall construction and a further 4.8 million homes with hard-to-treat cavity construction have no wall insulation. Current trajectories suggest that 80 to 85 per cent future housing stock in 2050 will be structures which already exist today; around three quarters of this will have been constructed before the introduction of thermal standards. Improving fabric efficiency across the nation’s housing stock is vital to achieving carbon and energy reduction targets and to alleviating fuel poverty and cold-related health impacts.
Government policy as a driver

Despite very recent instability in policy, the primary business model of nearly all SWI principal contractors in recent years has been securing and delivering contracts under government-led energy and emissions reduction programmes. These generally entail negotiations between contractors (or brokers) and the major energy companies in which contractors deliver a notional reduction in emissions through SWI for a negotiated price per retrofit.

This research took place in projects funded through the dominate UK policy instruments: the Energy Company Obligation (ECO), and to a lesser extent, Community Energy Savings Programme (CESP), Carbon Emissions Reduction Target (CERT), and Arbed.

Policy has driven dramatic growth in SWI in recent years; between 2009 and early 2015, annual rates of increase ranged from 30 to over 50 per cent (DECC 2013; DECC 2014; DECC 2015). The total SWI installations in the UK has recently been estimated at 338,960 (DECC 2015). In 2014, two policy instruments alone (the Energy Company Obligation and Green Deal Home Improvement Fund) (Committee on Climate Change 2015, pp. 22, 86) accounted for approximately 94 per cent of new installations.

Dowson et al. (2012) argue that policy will drive SWI more effectively if the current high cost (and long payback) of SWI is reduced. Although they rightfully call for technological innovation, this paper argues that workmanship and construction management are equally important to realising the national emission reduction potential of SWI.

Performance gaps and unintended consequences

The implications of poor specification and installation of SWI are severe. Risks include moisture ingress and vapour accumulation, interstitial and surface condensation, associated impacts on indoor air quality, loss of energy efficiency, and excessive summertime internal air temperatures. These carry implications not just for energy performance gaps and comfort, but also the integrity of existing building fabric, and hazards to occupant health. Further consequences include waste, site and non-site environmental impact, loss of aesthetic or cultural character, and mechanical failure. (Forman and Tweed 2014)

Mitigation of these risks requires that installers have appropriate levels of skill and understanding, and work within a system of effective training, certification and construction management.

Construction management: from intervallic inspection to quality assurance

Management in domestic new-build construction is widely recognised as less formalised and sophisticated than in other construction sectors. The Repair, Maintenance and Improvement (RMI) sector – and particularly domestic RMI – exhibit even stronger tendency toward this trend (Killip 2011).

Harris and McCaffer (2013) trace the evolution of quality management in UK construction over the past three to four decades from an inspection-based and ‘intervallic’ approach, to the continuous quality assurance (QA) model widely seen today. They argue that ideal management practices follow Total Quality Management (TQM) principles.

Civil engineering and commercial construction – as well as industries such as automobile, aerospace, and electronics manufacturing -- have internalised QA and TQM and the reduction of rework and call-backs for many years.

Research justification and research questions

Despite an abundance of manufacturers’ installation guidance, academic literature is almost devoid of documentation of actual SWI practices and of analysis of why these practices prevail, and of strategies for improvement. This work addresses this gap in literature.
Without previous theory or published observations to test, this work has assumed a qualitative ‘bottom-up’, interrogative and inductive approach that has developed questions iteratively.

Central questions this research addresses include:

- What characteristics does observed SWI exhibit?
- What appears to influence installation and specification quality?
- What are the barriers to improving practices?

Research methods and analysis

The research is most easily understood as proceeding through three stages of discovery.

In the first stage, exploratory interviews with 18 academic and professional experts working in a wide variety of professional roles provided contextual understanding.

This led to examining emergent themes through eight months of short rounds of non-participant observation and unstructured interviewing of actors (roughly 300 hours) in a diversity of roles, coupled with literature review. Interviews and discussions included:

- installation company management;
- energy company staff engaged with ECO;
- vocational trainers;
- National Vocational Qualification 2 (NVQ) external wall insulation (EWI) training and assessment;
- site managers;
- surveyors; and
- principal contractor officers in Arbed 2.

During this period, a full NVQ Level 2 training course was completed as a participant observer and essential proficiency in installation was developed.

In the final stage of research, 18 weeks of non-participant and participant observation were undertaken in a leading SWI installation company. Observation of contract managers and site managers and site inspection formed more than half of this phase. Additional periods (as participant and non-participant observer) spanning one to five days were spent with staff in nearly all occupational roles in the organisation, including: surveyors, senior management, business development and sales staff, and a generalist employee best described as a ‘technical overseer’ or ‘quality assurance officer’. Participant observation included two weeks of assisting in the training of NVQ Level 2 (NVQ2) candidates and four weeks working in the role of SWI installer.

Prior background as a builder and carpenter enabled a degree of assimilation in research settings, as well as informed analysis of observed practices.

Participants and sites

Professionals and institutions across central and southern England and southern Wales were included in the first two phases of research. The company in the third phase of research works across England and Wales. The vast majority of observation occurred in area-based retrofit projects (150-350 houses). Nearly all retrofits entailed EWI retrofit of 20th Century system-build construction. These sites appeared to dominate contracts across the industry during research.

COST Short-Term Scientific Mission

Two weeks were spent at the ‘Energy and Sustainable Development’ research group in the Faculty of Sciences at the University of Liege to observe retrofit research and visit several industry sites. This
took place in spring of 2013 and was funded through the COST Short-Term Scientific Mission programme, under the ‘Smart Energy Regions Action’. Belgium shares many similarities with the UK in climate, legislative drivers and building types.

Recruitment, access and informed consent

To provide a baseline insight into the research landscape, participants from a broad range of professional reputations, job roles and employers were recruited during initial stages. Participants were recruited from the broadest possible geographic area given practical constraints.

‘Snowballing’ was a factor in recruitment in the second and third phases of research. The company observed in the third phase was included during recruitment based on: its long history in the industry; its leading position in market share; and its indication that it was interested in improving practices (hence, observation promised to highlight drivers of and obstacles to change).

Generally, participants were not selected to serve as representative of a wider population; however participants assumed to be ‘outliers’ were typically not included.

Observation was limited by the number of actors and sites that could practically be included. Research captured roughly 100 experts and professionals and 1,000 in-process or newly-completed retrofits. Observation generally took place over several hours or days, but in some cases entailed only short conversation (i.e. between five and 15 minutes) or site inspection (i.e. several minutes). These shorter periods (not included in the above numbers) contributed to ‘saturation’ in analysis but have not provided a substantive basis for conclusions.

Analysis

All field notes and photographs were coded and codes were re-examined and refined during research. Codes were sorted by CAQDAS software and later by hand-sorting to arrive at categories and themes. These have been analysed against broader theory and literature.

Results

Findings included: persistent ‘quality gaps’ in workmanship; inappropriate specification practices; limited levels of formal or technical training; ineffective construction management practices; nascent professional identity; a lack of pride or motivation to achieve safe and effective retrofits; and numerous inadvertent impacts of policy on industry. This paper presents findings related to policy.

Policy: phenomena of ‘low hanging fruit’ and ‘gold rush mentality’

Contracts between contractors and energy companies are formed under essentially free market conditions, in which energy companies seek best ‘value’. Hence, contractors seek to maximise profit. This results in a ‘low hanging fruit’ scenario: the easiest and therefore most profitable projects will be in area-based projects in homogenous building stocks. A parallel issue where programmes such as ECO offered partial and complete funding for projects is that part-funded projects appeared to be disfavoured. This was explained by Contract Manager John as due to increased complexity of securing top-up funding and the greater demand from clients for accountability.

A ‘gold rush’ or ‘dash for cash’ phenomenon emerges: contractors seek to secure the most profitable projects and bring as many to practical completion as possible before relatively short funding periods expire (this is exacerbated by the unpredictability of weather suitable for EWI installation). Because of this, and because contracts are almost exclusively based on price per notional unit of energy or emissions reduction, a powerful incentive exists for principal contractors to prioritise ‘quantity over quality’. In turn, subcontractors – who are paid ‘pricework’ (pay based on insulated area) -- hurry to maximise their earnings (knowing that periods of boom are not constant) and to appease pressure from principal contractors.
Workmanship
Variability in workmanship between sites and installers existed, but typically significant faults were found in the majority of retrofits on sites.

For instance, insulation left exposed beneath window sills adjacent to door openings was observed five times across Phases 2 and 3. In three of these, the fault was not recorded by contract management. Figure 1 shows an example of insulation extended beyond a window sill and under-sill (which also has not been placed in line with the original sill as it should have been). This will certainly lead to moisture ingress.

![Figure 1 - Photograph of insulation board extended beyond sill and under-sill.](image)

All observed Internal Wall Insulation (IWI) installations displayed inadequate controls for internal vapour. In these installations, PUR or PIR were fixed directly to walls without any inner VCL and substantial gaps between insulation boards were common. These practices presented significant pathways for internal warm moist air to be driven outward, and so the risk of condensation against the inner face of walls (see Figure 2, which also shows incorrect placement of pins).
Figure 2 - Photograph showing large gap between IWI boards and incorrect locations of pins.

Figure 3 (overleaf) shows an example of poor treatment of a ‘bell’ (protrusion at base of wall) in an existing wall. The cavity that is visible here is likely to lead to thermal bypass or ‘convective looping’, as well as wind wash through openings in the base rail.

Figure 3 - Photograph of gap behind insulation board due to a ‘bell’ in existing wall.
Construction management

Observations found that management practices were based on essentially unstructured and periodic inspections. Senior management in all but one contracting organisation indicated that they relied heavily on ‘walk-arounds’ by site managers to ‘catch’ poor practice and determine retroactive solutions (i.e. rework). To a large extent, installers ‘self-regulated’ their work.

Nevertheless, some attempts by principal contractors to improve effective management were observed. This appeared rooted in two factors: first, with increasing business turnover there was a natural inclination toward achieving more effective cost control; and second, CESP and ECO (among other programmes) were introducing progressive requirements for auditing and documentation.

On balance, however, these shifts in practice did not appear to lead to well-managed projects. For instance, although principal contractors in ECO projects attempted to document stage completions (e.g. boarding or scrimming) in compliance with programme requirements, it was not common to observe inspections neatly aligned to stage completions.

Although policy instruments clearly were aiming to drive a shift toward more formalised management practices, they lacked the rigid controls necessary to trigger meaningful shifts in practice. Moreover, managers were typically former installers with little or no expertise in formal practice. In the absence of introduced training, tight requirements for documentation, and robust auditing of management, rudimentary and ineffective approaches to management appeared largely unchecked.

Training, assessment and qualification

Increased enrolment in formal installer training and qualification programmes was triggered by requirements in policy programmes for NVQ Level 2 qualification. In addition, to comply with guarantee and insurance policies, projects were generally required to include installers with product-specific training (one-day supplier-led ‘carding’).

Four weeks of participant observation in two NVQ training courses suggested that training placed a heavy emphasis on health and safety and site procedures (e.g. reporting incidents, finding relevant job documents), but failed to convey basic principles of insulation or minimisation of unintended consequences. It was consistently evident that understanding of important technical issues was limited among installers and many trainers.

Similarly, many managerial staff and ‘second tier’ professionals displayed these limitations. No training at a ‘higher’ level than NVQ2 was available.

Observation of assessment indicated that assessors were neither compensated adequately nor monitored in such a way as to ensure meaningful assessments were made. It appeared that cheating and short-cuts in assessment were rife.

Industry training is funded by an industry levy and the content of training is effectively directed by industry. This appeared to create a closed-loop cycle in which revision of training would only occur if recognition of inadequacy was voiced by industry. Consultation with experts outside this loop (for instance building scientists) appeared largely absent. Similarly, links between those who develop and deliver training and government departments which set the retrofitting agenda appeared weak at best. In other words, policy which drove retrofitting did not appear aligned with an industry training agenda to secure optimal performance of retrofits.

Guarantees and insurance

Policy programmes required that installations carried product warranties and latent defect insurance to cover installation practice.

Discussion with site and contract managers following observation of an inspection by an insurer’s auditor on an ECO project revealed worrying potential that warranties and insurance may not be supported by meaningful audits. In this observation, the auditor arrived to a 250-house retrofit
project to conduct one of five required inspections. He spent approximately 40 minutes on site, about half of which was spent in the site office verifying which properties were being insulated (he did not audit QA documents). He then briefly walked across one part of the site and conducted a hasty visual inspection of two pairs of neighbouring in-progress retrofits (each lasting less than two minutes). During this inspection, he missed several installation faults that would be considered ‘red flag problems’. From discussion with management and the auditor, this appeared to be typical practice. When this observation was relayed to Training Instructor John (a journeyman member of industry) he remarked:

“See that’s what it is isn’t it? It’s just... typical. What it should be is every house should have a number and should be photographed at every stage and every elevation and it should be tracked the whole way through. But at the moment, it’s like [auditors] don’t wanna know. It’s all about the numbers and they just wanna crank things through. Really, if it’s 60 houses, well that should be a week’s work to inspect all them.”

Discussion: the impacts of policy

The SWI installation industry can be characterised as a highly fragmented group of actors with generally unsophisticated construction management, limited technical understanding of risks, and inconsistent delivery of quality retrofits. This parallels findings made elsewhere in the RMI sector (Killip 2011).

Despite the imperative of national energy targets, while government policy has made significant steps toward driving SWI, it appears it is failing to ensure robust industry practices. This research shows how policy underlies some systemic problems across installation, management, training and insurance.

Policy drivers of SWI have a history of operating in short phases and imposing tight deadlines. Behind this are short-term commitments of funding from political or administration bodies and faltering alignment of political support. ‘Gold rushes’ have largely defined the SWI industry in recent years. A distinct lack of joined-up action between policy programmes, and between policy and industry appear to be thwarting improvement in quality and reliability.

Construction management

The complexity of risk factors in SWI and the critical importance of proper practices (for energy reduction, improved occupant health and comfort, and minimised embodied impacts of SWI) calls for robust construction management.

The mantra of ‘do it right and do it right the first time’ found elsewhere in engineering and construction does not appear embodied in SWI. As a result, poor installation practices are likely being propagated at scale.

In light of a lack of available training for SWI site and contract managers (or other managerial positions), it is perhaps unsurprising that generally primitive forms of management appear dominant. If policy does not provide the ‘push’ by requiring more meaningful auditing and documentation—and training to ensure managers are well-equipped is lacking -- there is little hope of a shift in the status quo.

De facto aspirations

Policy instruments set de facto quality aspirations by establishing norms such as required guarantee periods or prescribed QA procedures. Rather than serving as minimum acceptable standards, these become normative influences. For instance, the required 25-year guarantee under ECO (expanding the 10-year period in CESP) triggered efforts to improve build quality. Despite this, the requirement limits incentive for installers to build to higher standards and so aiming for longer service lives becomes unprofitable.
An alternative to this would be a form of energy performance contracting which would set payment to installation companies (or cost to funders) against longer service life or post-installation energy performance. This could be measured by periodic inspection, non-invasive testing or absence of call-backs or registered faults. Further bonuses could be provided for performance of maintenance or end-of-life recovery.

Current programmes pay installation companies in full at the start of service life. Coupled with short programme durations, this appears to reinforce inadvertently a culture of ‘short-termism’ while incentivising high output rather than quality.

Finally, policy that drives single-measure SWI belies the benefits of multiple-measure integrated retrofits. The implications of single-measure retrofits for occupant disruption, time and resource inefficiency and added cost are considerable.

False security: Failure to measure occupant satisfaction accurately and unreliability of insurance and guarantees

In a normal free market, sellers are incentivised to ensure buyer satisfaction by the prospect of return business or a strong reputation. Policy programmes supplant this mechanism and remove conventional ‘customer relationships’ between installers and occupants. Programmes which account for occupant and owner satisfaction over time are called for.

Collectively, funders, manufacturers, installation companies, installers, regulators and policymakers rely on a system of financial insurance against poor delivered quality. This system appears prone to failure if inspection and control of installation is inadequate and insurance audits are not robust enough to identify faulty installation or specification. Policymakers appear unaware that the current system is likely incapable of providing adequate insurance. Future policy instrumentation should ensure that reliable inspection and auditing systems are in place and that financial underwriting of insurance is adequate.

False security exerts an artificial condition: if the potential long-term consequences of practices are unrecognised or their cost deferred to future repayment, perceived present cost is significantly reduced. Failure to identify potential problems at installation normalises problematic practices. There is a grave risk of propagation across many tens of thousands of retrofits. The implications of large-scale failure are dire, and the potential costs of such failure may be measured in billions of pounds and significant implications for occupant health and environmental resources.

Opportunities for change

The vast majority of middle actors, particularly those at coalface positions have an infinitesimally small upstream influence (cf. Janda and Parag 2013). The direction of power between policymaker and building professional is overwhelmingly top-down and so mitigating artificial pressures in drivers will most expediently be changed by policymakers.

This is not to disregard the imperative for industry (at individual and collective levels) to equip itself to meet the challenge of large-scale SWI rollout more successfully. Killip (2011, p.289) presents a simple graphic to illustrate his argument that “policy-industry networks are key to the success” of energy efficiency improvements in the RMI sector (Figure 4). His argument is echoed by this research. It is vital that policy is closely informed by the realities of how industry deliver retrofits.
Training, too, needs to be aligned and this policy-industry-training alignment is hugely challenging. Meanwhile, contested ground between policy bodies, ‘silosiation’ across government (and industry and training), and political changeability has led to instability ‘at the coalface’. This has impeded growth toward a well-trained and managed industry. Financial investment in the technology of SWI as argued for by Dowson et al. (2012) must be accompanied by committed effort to ensure industry is supported but also controlled in order to assure it delivers retrofits of the highest quality.

Conclusion

Limitations of research

This work has developed new questions and theoretical explanations using qualitative methods. Akin to the ethnographic tradition from which these are derived, degrees of uncertainty, reflexivity and subjectivity are inherent in the research design. Additional work is needed to triangulate this research and address its limitations in generalisability and reproducibility. Moreover, this will address the restricted boundaries and scope of this research, which include duration, geographical setting, and the subset of industry included.

Reflection

In light of a reported legacy of inconsistent build quality and performance gaps in UK domestic SWI retrofitting, this research sought to improve understanding of practices. This is a topic about which essentially no literature has been published previously. This research documents a reasonably broad setting, offers new analysis, and provides future researchers and readers a basis for further work.

Despite significant growth, SWI installation remains at the fringes of the construction industry with low numbers of completed projects. Practices appear inconsistent and likely to engender risks of unintended consequences. This is likely to be partially attributable to the inadvertent impacts of the policy which has driven recent growth.

There is no reason to doubt that policy can drive growth while also creating the conditions necessary to support high-quality retrofits.

Shortcomings in training and certification programmes, management practices and guarantees call for concerted action rather than a laissez-faire and gradual approach to improvement. If the government chooses to resume its concerted effort to drive SWI – and the imperative of doing so is clear – it must make certain that strategies and resources are aligned appropriately to ensure optimal retrofits.


References


Funding acknowledgement

This paper is based on doctoral research conducted by Tim Forman at the Welsh School of Architecture of Cardiff University between 2011 and 2015 under the supervision of Professor Chris Tweed. The research was funded by the Engineering and Physical Sciences Research Council and the Building Research Establishment. During this work, a COST-funded STSM titled ‘Thermal insulation retrofitting: theory and practice’ (TU1104-13597) under the Smart Energy Regions Action enabled research exchange and a visit to the ‘Energy and Sustainable Development’ research group in the Faculty of Sciences at the University of Liege between May and June 2013.
Planning of cost-effective and energy-efficient retrofitting actions: a comprehensive energy audit approach

Rossano Albatici 1, Alessia Gadotti 1, Christian Baldessari 2, Michela Chiogna 3

1) Department of Civil, Environmental and Mechanical Engineering, University of Trento, Via Mesiano 77, 38123 Trento, Italy
2) Baldessari Ingegneri Srl, Strada del Dòs Grum 18, 38123 Trento, Italy
3) Istituto Trentino per l’Edilizia Abitativa SpA, Via Guardini 22, 38121 Trento, Italy
Corresponding author: Rossano Albatici, rossano.albatici@unitn.it

Abstract: Buildings in Europe account for 40% of total primary energy consumption and 36% of greenhouse gas emissions. Approximately 40% of Europe’s building stock predates the 1960s (in Italy the percentage increases to 63.8% considering the 1970s), when standards regarding insulation, energy efficiency and indoor comfort did not exist, and the stock is now in dire need of renovation. New construction in Europe represents only about 1% of the building stock, and in the last 15 years, the market of urban refurbishment has constantly increased. Up to now, an accepted and consolidated methodology for refurbishing the existing housing stock is still missing, despite the amount and quality of technologies, components and materials available. Every intervention is considered as specific and subject to a wide range of variables.

The purpose of the present study is to present a working approach for optimising the retrofitting process, from an energetic and a cost-effective point of view and considering users’ comfort, through an analysis procedure of the existing building stock, adaptable to different contexts. In particular, this paper refers to the building stock of ITEA SpA, the Social Housing Institute for the Province of Trento (Italy), which manages more than 16,000 housing units. The research can be summarized in four main phases: definition of clusters, in which buildings are similar in terms of age, dimensions, typology, construction system and location within the region Trentino; analysis of building-plant systems solutions and recognition of significant cases for classifying buildings in term of energy class; identification of possible improvements and related cost-benefits; extension of the results to the whole cluster. The aim is to set medium and long term plans taking into account possible benefits on management costs and therefore the effective sustainability of intervention for the controlling body (cost effectiveness) and the final user (energy efficiency and comfort quality).

Keywords: energy retrofitting, sustainable intervention, social housing, energy performance

Introduction

Buildings in Europe account for 40% of total primary energy consumption and 36% of greenhouse gas emissions. Recent studies confirm this assumption taking into consideration Italian municipalities where approximately 37% of the emission are due to housing [1]. Moreover, in most EU countries new constructions are less than 1% per year of the building stock, and the impact of energy regulations are limited and not sufficient if not extended to existing buildings [2]. An accepted and consolidated methodology for refurbishing the existing housing stock is still missing, despite the amount and quality of technologies, components and materials available. Every intervention is considered as specific and subject to a wide range of variables. In a period of notable lack of public resources as well as contraction of public expenditure, it is important to define possible interventions considering both technical and economical feasible solutions for the management of a wide building stock often obsolete and expensive to maintain. In addition, the European Directive 2010/31 stresses that energy retrofitting should aim “to achieve cost-optimal levels” [3].
In recent years, several researches have attempted to fill in the gap. Wang and Holmberg [4] propose an approach to design and assess energy demand retrofitting scenarios based on representative archetypes, energy modelling and LCCA (Life Cycle Cost Analysis)-based cost-effectiveness estimations. Mauro et al. [5] propose a novel methodology that supports a robust cost-optimal analysis of energy retrofit solutions for a building category through a simulation-based large scale uncertainty/sensitivity analysis. Jaggs and Palmer [6] present a methodology developed within the European project EPIQR with the aim to assist apartment building owners who are considering refurbishment and retrofitting (upgrading) their building stock. Ma et al. [7] try to provide a systematic approach to proper selection and identification of the best retrofit options for existing buildings.

However, other important aspects should be taken into account. First of all, the leading role of public bodies, or those who manage public administration, in planning interventions and in considering, proposing and realizing solutions with a wide impact on the territory, in terms of employment, microeconomic viability but also environmental advantages (on a macro and micro scale). In fact, “Public administrations are called upon to take on a pivoting role in the energy efficiency sector of existing buildings” due also to their high visibility in public life [8], as explicitly mentioned in the European Directive 2006/32 [9].

Energy retrofitting of existing buildings to new energy standards, in addition to allow cost savings, use less fuel and therefore the reduction of greenhouse gases in the atmosphere (with measurable effects concerning air pollution and urban heat island), can provide better comfort conditions in living spaces. In fact, improved building envelopes decrease heat losses for transmission and ventilation and guarantee a more uniform temperature distribution, less inner radiant asymmetry, lower air leakage and so better general thermal comfort conditions (usually mainly due to radiant heat exchange). The use of materials with higher technical performances and a renewed attention to windows, can bring direct benefits also by an acoustic, visual and indoor air quality point of view. Flexible heating systems, easily controllable by the users, can lead to a psychological feeling of excellent inner microclimate, further increasing users’ satisfaction. It’s the so-called “green retrofitting”, consisting of passive systems technologies and use of eco-compatible, recycled or recyclable materials [8].

**Aim of the research**

In this complex framework, the purpose of this study is to present a working approach for optimising the retrofitting process, from an energetic and a cost-effective point of view whilst considering users’ comfort, through an analysis procedure of the existing building stock, adaptable to different contexts.

In particular, this paper refers to the building stock of ITEA S.p.A. (ITEA hereinafter), a capital company directed and coordinated by the Autonomous Province of Trento. Its main task is the construction, refurbishment, acquisition and management of buildings for social housing, mainly for residential use but considering also annexes (such as shopping areas, schools, kindergartens, theatres, gyms, and so on). Up to now, it manages more than 16,000 housing units (corresponding to 645 buildings, see Table 1) located in the territory of the province of Trento, Italy.

The aim of the research, which began in 2014, is to conduct a technological-economic analysis of feasible measures to apply on the existing housing stock managed by the company, in order to improve their energy efficiency in terms of total energy demand, both from renewable energy sources or not. The purpose is to develop a multiannual plan of retrofitting interventions through managed and organised suitable strategies, based on the improvement options identified during the analysis phase. In this way, costs and benefits can be estimated with their impact on administrative expenses for asset management depending on the type of measure selected, prioritising the retrofit alternatives.
Methodology

The wide building stock managed by ITEA consists of apartments both built by the company and acquired from third parties in the Trentino region, which is widely differentiate, with a climate that could be defined as transitional between semi-continental and alpine. Therefore it becomes rather complex to define a univocal methodology analysis of the existing assets. On this basis, an overall systematic analysis has been carried out, according to the procedure briefly described below:

a. Evaluation of the existing building stock assessing its energy efficiency, differentiated by representative types of building in terms of age, dimension, typology, construction system and location within the Trentino region.

b. Analysis of the envelope and the equipment on a sample of buildings for each type earlier identified, in order to benchmark building energy use by using selected indicators that correlate energy performance class with building type and components.

c. Identification of intervention options classes, feasible for each building type, aimed to energy enhancement, with attention to the cost-efficiency of measures. In particular, costs and paybacks related to each type of option are estimated, defining the achievable energy performance class. A tool useful to set up appropriate medium and long-term intervention plans is proposed.

d. Ex-post evaluation of undertaken retrofit measures, verifying the effective achievement of the objectives planned in the diagnostic stage, through at least one year long monitoring of the examined buildings energy demand.

Definition of clusters

The ITEA building stock is the product of the construction activity carried out by the company over the years and of inclusions gained from various suppressed public and private entities, which merged into the assets of the company according to local and national regulations. As result, ITEA manages buildings that are mostly older than 30 years.

Table 1 shows a first classification of the company properties with respect to the age of the housing stock. Five classes have been identified. Almost 50% of buildings were built right after the Second World War, with the reconstruction of the territory and the necessity to accommodate many displaced families, before the first Energy Saving Law 373/76 [10] referring to the heating energy consumption savings and improvements in energy efficiency. Nearly one third of the existing assets were built between 1981 and 1991, year of promulgation of the Italian law regarding the rational use of energy, energy saving and development of renewable sources [11].

Therefore, except in those cases where enhancing envelope measures have already been undertaken, most buildings are quite old and highly energy-intensive.

Table 1 - Focus on ITEA S.p.A. stock: number and percentage of buildings in terms of age.

<table>
<thead>
<tr>
<th>Age</th>
<th>Number of buildings</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ante 1945</td>
<td>21</td>
<td>3%</td>
</tr>
<tr>
<td>1945 - 1980</td>
<td>265</td>
<td>41%</td>
</tr>
<tr>
<td>1981 - 1991</td>
<td>209</td>
<td>33%</td>
</tr>
<tr>
<td>1992 - 2000</td>
<td>72</td>
<td>11%</td>
</tr>
<tr>
<td>Post 2000</td>
<td>78</td>
<td>12%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>645</td>
<td>100%</td>
</tr>
</tbody>
</table>
In order to achieve a systematic and complete framework of the building clusters in terms of energy efficiency, the following data has been collected for 25 representative buildings:

a. Floor number: high (above 8) – medium (between 4 and 7) – low (between 1 and 3);
b. Building type: terraced houses, tower buildings, block buildings, apartment buildings;
c. Position: isolated, aggregated;
d. Structural components (envelope): not insulated walls, external insulated walls, layered walls with insulation in the cavity, prefab concrete panels;
e. Year of construction (with the age categories as indicated in Table 1);
f. Site location: valley floor (0-250m), medium altitude (250-750m), mountain (above 750m), taking into account also the different municipalities total Degree Days.

Worksheets have been completed (see example at Figure 1) where the following data is reported:

1. Building image and identification code number;
2. Components cross-section and technical data: external wall, floor slab of the roof-space, floor slab (heated volume enclosing elements);
3. windows typology;
4. main heating system;
5. heat generator;
6. heat regulation system;
7. heating fuels.

Fig. 1 - Example of worksheet for the classification of representative buildings of the different identified classes.
Analysis of the building and its equipment and energy classification

The analysis of the envelope components and systems of the 25 selected buildings stet:

a. For each building, the original architectural and structural project have been recovered. A matrix has been created where all the collected information are synthetized, with regard to location, building type and construction type, geometric data (heated surface and volume), envelope components and materials, windows (material, frame, shading devices), thermal and electrical systems features and consumption data (when a centralized remote reading system is present).

b. Secondly, site visits were conducted to verify the compliance of the documentary theoretical data with the actual buildings. Geometrical surveying of significant parts of the buildings have been carried out on a random basis, and the exposure and presence of shading elements have been verified. In addition, structural materials have been verified and window and doors performance have been confirmed with specific tools. Conditions of the mechanical systems have been evaluated, from the power unit to the heating appliances (presence of thermostatic valves or other thermal input local control devices, thermostats type etc.), and annual heating and electric energy consumption values have been collected, by randomly surveying apartments’ occupants.

c. The third step has evaluated the building envelope thermal performance measuring walls thermal transmittance U-value with infrared thermography methodology developed in an earlier research [12]. This procedure, apart from giving a numerical value of the wall transmittance, helped to verify the buildings deterioration and the presence of thermal bridges or air leakages (with indoor thermography).

Once verified the actual asset of the buildings sample, steady-state numerical modelling has been conducted according to UNI/TS 11300:2008 part 1 and 2 [13-14] and UNI/TS 11300-4:2012 [15]. Opaque and transparent building envelope components have been considered, including elements dividing housing units. Different units have been modelled individually and univocally defined by different thermal zones giving the opportunity of comparing performance in terms of exposure and use, providing an objective methodology, as far as possible, in the choice of the most disadvantaged buildings for evaluating following retrofit actions. A steady-state analysis has been preferred to a dynamic one as the latter is more laborious and time consuming and requires a larger amount of data inputs (including the TRY – Test Reference Year often not available). These are often difficult to achieve, and precise occupant schedules, often unknown, are not theoretically conceivable. In addition, in wintertime when thermal capacity loses importance, a faster and simpler steady-state method to be implemented provides good results in terms of deviation from the real values of energy consumption. It is also known that dynamic procedures are sophisticated techniques, which do not seem appropriate to be applied on rather old buildings, whose real physical and technical materials and systems data are not known or are different than those declared in the design documents. Another important issue is that the research methodology has as purpose to be useful to the funding body and replicable for further applications by technicians in a simple and fast way.

For each building, the energy demand has been evaluated for production of sanitary water, heating and electricity demand, expressed in kWh/y. These values have then been compared to those monitored, and have achieved a good agreement. Therefore, energy key performance indicators have been evaluated in terms of power, grouped by elements (opaque elements, transparent elements, thermal bridges) and by exposure, to separate the impact of each component on building heat losses and to give a first indication on feasible enhancing measures for energy retrofitting.

So, the actual effective conditions of the building sample has been confirmed and theoretical energy performance has been determined, with calibrated and corrected input data taking into account the real degradation, use and maintenance state of the buildings.
Evaluation of feasible retrofit options

A simple and interactive tool has been developed, able to simulate possible retrofit scenarios showing costs and investment return time associated with each solution.

To test the tool potentiality and to obtain first indications for defining future technical-economic planning strategies, some retrofit options for the 25 buildings have been identified, based on the site visit where the main lack of the buildings considering energy performance have been surveyed and the possible solution have been proposed. An economic analysis has been performed as well to determine the most cost effective technologies among those usually applied by ITEA (local suppliers in respect of materials and labour, timing and category of intervention).

The feasible measures have been subdivided in two types.

Interventions on the building envelope include:

a. external insulation with 10 cm layer thickness of polyurethane (λ=0.031 W/mK);

b. windows and doors replacement (total replacement with Uw = 1.1 W/m²K or glass replacement only, with a 4-12-4-12-4 and Ug = 0.70 W/m²K triple-pane glass);

c. insulation of slabs over unconditioned spaces (ground floor slab and non-habitable roof-space slab) with 8 cm layer thickness of polyurethane (λ =0.036 W/mK).

d. Interventions on heat generation and regulation systems include:

e. installation of thermostatic valves on radiators with independent remote control system (it should be noted that the Italian legislative Decree transposing the European directive 2012/27/EU requires radiators to be equipped with thermostatic radiator valves starting from the end of 2016 in multi-apartment buildings supplied by district heating or common central heating);

f. replacement of the existing boiler with a condensing boiler (independent or centralized) or with a biomass boiler (the latter technology is feasible only in building provided with a diesel heating system);

g. installation of roof solar thermal panels, where feasible (measure proposed only in buildings supplied by common central heating).

For each one of the 25 selected buildings, feasible retrofit measures have been analysed individually or combined with others, defining for each scenario energy performance indexes and parameters specified above (the achievable total energy demand, the reachable energy performance class, and the investment costs).

Potential overall savings in terms of future management costs and payback time are estimated considering both the amount of fuel saved and its average cost (see Table 2). The annual inflation rate (equal to 0.2% for 2014) and the amount due have been considered to define the capitalisation rate of initial investment, following an opportunity cost approach that evaluates the benefits that could have been received by taking alternative actions from those considered. In this case, the expected return has been determined used the returns rate on long-term (30 years) government bonds (average value: 3.0%).
Table 2 - Average cost of fuel per unit of energy generated (first 3 columns) and pre unit of fuel consumed (last column).

<table>
<thead>
<tr>
<th>Fuel</th>
<th>2011/2012 €/kWh</th>
<th>2012/2013 €/kWh</th>
<th>2013/2014 €/kWh</th>
<th>2013/2014 €/mc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>0.08010</td>
<td>0.08610</td>
<td>0.09255</td>
<td>0.91991</td>
</tr>
<tr>
<td>diesel</td>
<td>0.12740</td>
<td>0.12959</td>
<td>0.13182</td>
<td>1.56475</td>
</tr>
<tr>
<td>LPG</td>
<td>0.17560</td>
<td>0.19051</td>
<td>0.20668</td>
<td>2.64098</td>
</tr>
<tr>
<td>District heating</td>
<td>0.10510</td>
<td>0.11297</td>
<td>0.12143</td>
<td>0.12143</td>
</tr>
</tbody>
</table>

Table 3 shows the length of the period of return on investments (payback time), expressed in years, for the 25 buildings per considered retrofit option. Boxes are left blank if measures are considered not feasible in practice. Table 3 illustrates that the interventions with higher average payback time (being 30 years the acceptable limit) are:

a. external insulation system, with only 8 cases below the acceptable limit (keeping in mind that 4 buildings, 12-15-22-23, have already an adequate thermal insulation). The main factor influencing total cost is scaffolding, which is particularly onerous for medium-large size buildings and represents up to one third of the total cost;

b. window and door replacement, with no cases below acceptable limit. This indicates that this measure is not viable if applied alone without external insulation;

c. insulation of the ground floor slab, with 10 cases below the acceptable limit;

d. installation of condensing boiler, with 10 cases below the acceptable limit, out 20 considered, regarding buildings with centralized system, more manageable.

e. Payback time is acceptable (below 30 years) on investments related to insulating of the non-habitable roof-space, with only 4 cases exceeding it, due to the presence of an existing envelope with good thermal performance. Low payback time is also achieved with:

f. installation of solar panels, essentially for water heating;

g. installation of thermostatic valves on radiators, minor and low-cost measure in terms of materials and skilled labour;

h. replacement of the existing boiler with biomass boiler, very beneficial since the unit cost of energy production with wood pellet states around 0.05 €/kWh.

In addition to the period of return on investments, it should be obviously considered the achievable effective energy savings.

A good energy saving (20.4%) can be obtained with biomass boiler and with thermostatic valves (15.5%), which have very fast payback time and therefore are measures to which attention should be paid, considering that application of thermostatic valves is a fast and low-cost procedure.

Retrofitting the building envelope fabric with external insulation provides more benefits in terms of primary energy demand (with an average value of 23.5%) since it reduces heat loss through walls, which are poorly performing elements with a large surface. This percentage is very similar to that obtained by dall‘O’ et al [1] stating that “just considering the envelope retrofitting it is possible to reduce energy used by residential sector up to 24.8% in 2020”.

Table 3 - Payback years and the percentage variation of heating energy demand, for each building and for each retrofit option.

<table>
<thead>
<tr>
<th>Building</th>
<th>a</th>
<th>b</th>
<th>c1</th>
<th>c2</th>
<th>d</th>
<th>e1</th>
<th>e2</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>y</td>
<td>%</td>
<td>y</td>
<td>%</td>
<td>y</td>
<td>%</td>
<td>y</td>
<td>%</td>
</tr>
<tr>
<td>1</td>
<td>41.8</td>
<td>35.2</td>
<td>210</td>
<td>6,2</td>
<td>113</td>
<td>2,1</td>
<td>112</td>
<td>2,3</td>
</tr>
<tr>
<td>2</td>
<td>24.4</td>
<td>28.9</td>
<td>71,9</td>
<td>8,8</td>
<td>7,5</td>
<td>5,5</td>
<td>33.9</td>
<td>2,9</td>
</tr>
<tr>
<td>3</td>
<td>17.7</td>
<td>23.2</td>
<td>77,4</td>
<td>10,9</td>
<td>30.9</td>
<td>2,8</td>
<td>69.0</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>19.4</td>
<td>26.9</td>
<td>52.9</td>
<td>11.4</td>
<td>8.4</td>
<td>8.2</td>
<td>24.9</td>
<td>6.6</td>
</tr>
<tr>
<td>5</td>
<td>13.8</td>
<td>25.3</td>
<td>45.2</td>
<td>7.6</td>
<td>9.1</td>
<td>6.1</td>
<td>26.0</td>
<td>5.1</td>
</tr>
<tr>
<td>6</td>
<td>15.4</td>
<td>32.9</td>
<td>57.5</td>
<td>8.8</td>
<td>12.1</td>
<td>4.8</td>
<td>23.3</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>31.6</td>
<td>26</td>
<td>114</td>
<td>8.9</td>
<td>29.5</td>
<td>3.5</td>
<td>31.5</td>
<td>7.8</td>
</tr>
<tr>
<td>8</td>
<td>16.8</td>
<td>26.4</td>
<td>55.1</td>
<td>7.3</td>
<td>13.1</td>
<td>5.4</td>
<td>38.8</td>
<td>4.3</td>
</tr>
<tr>
<td>9</td>
<td>41.8</td>
<td>14</td>
<td>56.7</td>
<td>8.3</td>
<td>16.3</td>
<td>4.7</td>
<td>27.1</td>
<td>6.9</td>
</tr>
<tr>
<td>10</td>
<td>33.0</td>
<td>16.4</td>
<td>48.2</td>
<td>8.1</td>
<td>9.5</td>
<td>7.5</td>
<td>24.2</td>
<td>7</td>
</tr>
<tr>
<td>11</td>
<td>20.3</td>
<td>28</td>
<td>49.8</td>
<td>8.3</td>
<td>8.9</td>
<td>5.8</td>
<td>26.1</td>
<td>4.8</td>
</tr>
<tr>
<td>12</td>
<td>63.8</td>
<td>10.6</td>
<td>64.8</td>
<td>23.3</td>
<td>45.1</td>
<td>1</td>
<td>41.6</td>
<td>4.1</td>
</tr>
<tr>
<td>13</td>
<td>33.7</td>
<td>17.5</td>
<td>106</td>
<td>7.7</td>
<td>11.4</td>
<td>2.6</td>
<td>22.6</td>
<td>5.6</td>
</tr>
<tr>
<td>14</td>
<td>35.1</td>
<td>21.9</td>
<td>64.6</td>
<td>11.1</td>
<td>34.7</td>
<td>3.1</td>
<td>25.8</td>
<td>9.9</td>
</tr>
<tr>
<td>15</td>
<td>87.3</td>
<td>17.5</td>
<td>101</td>
<td>15.4</td>
<td>124</td>
<td>0.9</td>
<td>77.2</td>
<td>3.1</td>
</tr>
<tr>
<td>16</td>
<td>7.5</td>
<td>45.7</td>
<td>40.6</td>
<td>5.1</td>
<td>9.1</td>
<td>2.2</td>
<td>14.1</td>
<td>4.7</td>
</tr>
<tr>
<td>17</td>
<td>35.4</td>
<td>29.3</td>
<td>93.6</td>
<td>9</td>
<td>26.3</td>
<td>5.2</td>
<td>45.6</td>
<td>6.9</td>
</tr>
<tr>
<td>18</td>
<td>48.4</td>
<td>29.2</td>
<td>159</td>
<td>7.2</td>
<td>49.9</td>
<td>3.9</td>
<td>76.5</td>
<td>4.6</td>
</tr>
<tr>
<td>19</td>
<td>49.2</td>
<td>18.8</td>
<td>91.2</td>
<td>8.8</td>
<td>13.7</td>
<td>9.7</td>
<td>61.5</td>
<td>6.2</td>
</tr>
<tr>
<td>20</td>
<td>20.4</td>
<td>25.8</td>
<td>41.5</td>
<td>10.8</td>
<td>19.5</td>
<td>1.9</td>
<td>25.3</td>
<td>5.1</td>
</tr>
<tr>
<td>21</td>
<td>48.7</td>
<td>12.7</td>
<td>49.7</td>
<td>15.1</td>
<td>50.4</td>
<td>3.6</td>
<td>20.8</td>
<td>5.9</td>
</tr>
<tr>
<td>22</td>
<td>63.3</td>
<td>20.4</td>
<td>150</td>
<td>7.5</td>
<td>57.8</td>
<td>5.6</td>
<td>74.5</td>
<td>5.7</td>
</tr>
<tr>
<td>23</td>
<td>249</td>
<td>2.3</td>
<td>58.7</td>
<td>13.4</td>
<td>48.0</td>
<td>0.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>24</td>
<td>46.8</td>
<td>21.6</td>
<td>108</td>
<td>6.3</td>
<td>31.6</td>
<td>3.9</td>
<td>67.8</td>
<td>1.7</td>
</tr>
<tr>
<td>25</td>
<td>40.1</td>
<td>32</td>
<td>109</td>
<td>6.5</td>
<td>32.6</td>
<td>3.7</td>
<td>63.0</td>
<td>4.7</td>
</tr>
<tr>
<td>average</td>
<td>44.2</td>
<td>23.5</td>
<td>83.2</td>
<td>9.7</td>
<td>29.8</td>
<td>4.2</td>
<td>43.3</td>
<td>5.1</td>
</tr>
</tbody>
</table>
The tool has indicated that other measures have low impact on energy savings and it is therefore not appropriate to consider them individually.

However, whenever it is decided to set up a management plan for building retrofits, joint and multiple solutions could be applied to minimize the impact on fixed execution costs. For this purpose, the following possible combinations have been considered:

i. external insulation with window and door replacement;

j. as solution g plus insulation of the non-habitable roof-space slab;

k. as solution h plus thermostatic valves replacement;

l. as solution i plus biomass boiler (when feasible).

The results, considering the combined interventions, are shown in Table 4 where the average, minimum and maximum value of heating energy demand are highlight.

Table 4 - Percentage variation of heating energy demand for combined interventions.

<table>
<thead>
<tr>
<th></th>
<th>g</th>
<th>h</th>
<th>i</th>
<th>j</th>
</tr>
</thead>
<tbody>
<tr>
<td>average</td>
<td>36.6</td>
<td>40.64</td>
<td>50.5</td>
<td>60.8</td>
</tr>
<tr>
<td>minimum</td>
<td>34.1</td>
<td>35.9</td>
<td>47.3</td>
<td>59.4</td>
</tr>
<tr>
<td>maximum</td>
<td>39.1</td>
<td>44.9</td>
<td>53.9</td>
<td>62.3</td>
</tr>
</tbody>
</table>

Going from g to j, the percentage variation of heating energy demand increases, that is the intervention is surely more appropriate for preserving the environment with a reduced use of energy sources. Taking into account that thermal energy from renewables is more or less the 7% of the total thermal energy produced in Italy (data from 2011), CO$_2$ emissions can be reduced up to 55%.

The number payback years usually increase considering intervention g and h (from 3 to 8 years usually, depending on the building class analysed), while in the majority of cases considering intervention i and/or j the investment in retrofitting measures becomes more attractive, even if the initial cost is higher.
Table 5 - Estimated costs for the analysed retrofit options, in thousands €.

<table>
<thead>
<tr>
<th>Building</th>
<th>Retrofit options</th>
<th>TOT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>1</td>
<td>51.7</td>
<td>45.8</td>
</tr>
<tr>
<td>2</td>
<td>87.3</td>
<td>78.1</td>
</tr>
<tr>
<td>3</td>
<td>53.9</td>
<td>110.3</td>
</tr>
<tr>
<td>4</td>
<td>80.1</td>
<td>93.0</td>
</tr>
<tr>
<td>5</td>
<td>69.7</td>
<td>68.2</td>
</tr>
<tr>
<td>6</td>
<td>97.3</td>
<td>96.8</td>
</tr>
<tr>
<td>7</td>
<td>86.0</td>
<td>107.1</td>
</tr>
<tr>
<td>8</td>
<td>102.4</td>
<td>93.2</td>
</tr>
<tr>
<td>9</td>
<td>40.9</td>
<td>33.1</td>
</tr>
<tr>
<td>10</td>
<td>79.9</td>
<td>58.1</td>
</tr>
<tr>
<td>11</td>
<td>58.7</td>
<td>42.7</td>
</tr>
<tr>
<td>12</td>
<td>79.8</td>
<td>178.9</td>
</tr>
<tr>
<td>13</td>
<td>81.3</td>
<td>112.5</td>
</tr>
<tr>
<td>14</td>
<td>39.0</td>
<td>36.5</td>
</tr>
<tr>
<td>15</td>
<td>79.8</td>
<td>81.6</td>
</tr>
<tr>
<td>16</td>
<td>33.8</td>
<td>20.5</td>
</tr>
<tr>
<td>17</td>
<td>69.1</td>
<td>56.1</td>
</tr>
<tr>
<td>18</td>
<td>224.8</td>
<td>183.2</td>
</tr>
<tr>
<td>19</td>
<td>213.4</td>
<td>184.9</td>
</tr>
<tr>
<td>20</td>
<td>58.8</td>
<td>49.9</td>
</tr>
<tr>
<td>21</td>
<td>53.9</td>
<td>65.1</td>
</tr>
<tr>
<td>22</td>
<td>357.4</td>
<td>312.3</td>
</tr>
<tr>
<td>23</td>
<td>225.4</td>
<td>315.5</td>
</tr>
<tr>
<td>24</td>
<td>81.7</td>
<td>55.9</td>
</tr>
<tr>
<td>25</td>
<td>66.3</td>
<td>36.6</td>
</tr>
<tr>
<td><strong>TOT</strong></td>
<td><strong>2472.4</strong></td>
<td><strong>2515.9</strong></td>
</tr>
</tbody>
</table>

To intervene over the next 5 years across 30% of the buildings managed by the company and considering 25 buildings sample as representative of the different types until year 2000, the cost for the energy retrofitting of 189 buildings (that is, 567 buildings divided by three, please refer to Table 1) would amount to € 53,000,000, equivalent to € 5,300,000 per year. The last part of the research, still on going, regards the development of an inventory of ITEA building stock based on the representative building types previously defined. It will be possible to scale-up the retrofit simulation and to have a clearer picture of costs and time-frame, better defining the numbers previously presented.

Following this research project, ITEA received in December 2015 a financial contribution of € 2,100,000 from the Province of Trento to undertake the necessary energy retrofitting actions of 406 apartments (corresponding to 46 buildings) through form of public-private partnerships. The ten years total investment cost amounts to € 7,357,998, among which € 5,257,998 are from private capital. With the elaboration of this intervention plan, it has been possible to conjugate two very important aspects for ITEA and for the private investors: to collect data from a specific calculation regarding costs, achievable savings and payback time; to execute retrofitting works at the same time with other necessary actions on buildings envelope, optimizing costs, especially as regards scaffoldings. Furthermore, a potential energy performance contractor of ITEA may benefit from various types of
local or national contributions and fiscal benefits, which contribute to further reduce payback of the investment.

In fact, considering solely payback time and without taking into account environmental and user’s comfort advantages, energy retrofitting interventions are uneconomical, especially for old and large buildings. Some funding possibilities already exist, hereafter mentioned:

1. tax benefits, linked to the intervention quality and effectiveness, that allow to partially recover the costs (from 50 to 65%) in a fixed period of time (usually 10 years);
2. soft loans received as public contributions (0.50% per year) for a maximum of 6 years (15 for public bodies), repayable in semi-annual instalments (so called “Kyoto Fund”);
3. ESCo, Energy Service Company, that covers the costs of the interventions (objectives and services) that will be repaid by part of the savings as agreed with the owner. The Company can gain money only if the interventions are profitable, so it is encouraged to act in the most efficient way as possible.

Conclusions and future developments

This paper illustrates how it is possible to realise a simple but effective tool for the management of the building stock of a social housing company, integrating meaningful building classes, generalising the results and planning and analysing possible intervention scenarios. Technical solutions have been considered and their costs and payback give useful indications in order to define interventions and budget commitments for long-term projects. Other public bodies managing residential or commercial buildings (municipalities, for example) can use the tool in order to enhance the building energy performance and to save money for their maintenance. Private companies or building manager associations can get useful information to propose flat owners long term plans for investment in the building energy saving.

It has been pointed out that public tax policies and incentives are still necessary in order to drive the market towards those energy retrofitting actions which have clear environmental and comfort meaning, but low economic appeal. Moreover, these policies could help the building sector in a period of deep crisis facilitating the birth and growth of new companies as, for example, the ESCos.

In addition, proper management of the building stock is based on continuous maintenance operations, whose costs increase considerably with the increase of the buildings age. So, it is often convenient to realise expensive works but effective by a structural and energy point of view, at least in the medium-long period.

In addition to defining a multiannual plan of retrofitting interventions through managed and organised suitable strategies, the proposed tool will be used by ITEA to take concrete action towards a more accurate and sustainable buildings management. It is also required by its public role and the resulting indirect responsibility towards the people and the territory. Moreover, the economic value of the buildings will be improved. Apart from the tangible monetary energy savings, ITEA will have the possibility to revise downwards the rents of a certain amount, on condition that tenants participate in energetic spending of not yet retrofitted buildings. In this way, tenants will be directly involved generating a shared responsibility towards the environment and ITEA itself, and efforts will be capitalised by sharing the expenses, allowing to program further retrofitting plans.

A possible future development of this research is to take into consideration the green retrofitting approach, looking not only at the energy aspects (envelope and systems) but also at the use of renewable energy, passive systems and the LCA of building materials and elements. It will be equally important to define possible inclusion policies of the users so to drive their behaviour towards more sustainable and environmental friendly building operations, since occupants have a strong influence on both energy consumption and the indoor environment [16].
During Spring 2016 the quality of the proposed tool will be verified by means of Measurement and Verification (M&V) actions of energy savings, monitoring the energy consumptions and the inner comfort conditions of part of the 25 buildings previously analysed that have been retrofitted over the past 6 months.

Acknowledgments

The research presented in this paper has been funded by ITEA and cofunded by the Autonomous Province of Trento - Italy. The authors would like to thank eng. Giulio Giacomelli, former Property Management Sector executive of ITEA, and his staff for the valuable contribution during the research development.

References


[10] National Law 30th March 1976, n. 373, Regulations on the limitation of thermal energy consumption in buildings, in Italian

[11] National Law 9th January 1991, n.10, Regulations for the implementation of the national energy plan in the field of the rational use of energy, energy saving and development of renewable energy, in Italian


Improving the district heating system in Belgrade - towards smart energy consumption

Aleksandra Krstic-Furundzic 1, Aleksandra Djukic 2, Milan Petrovic 3

1) Faculty of Architecture, University of Belgrade, Bulevar kralja Aleksandra 73/II, Belgrade, Serbia, akrstic@arh.bg.ac.rs
2) Faculty of Architecture, University of Belgrade, Belgrade, Serbia, adjukic@rcub.bg.ac.rs
3) PUC Beogradske elektrane, Savski nasip 11, Belgrade, Serbia, milan.petrovic@beoelektrane.rs

Abstract: An efficient system of district heating is the element of a sustainable building that determines a comfortable indoor microclimate. District heating supply exists in 55 towns in Serbia. In Belgrade 50% of apartments and houses are covered with it.

At the moment, the Public Utility Company “Beogradske elektrane” uses lump billing method for collection for heating per square meter of residential space. Such billing method does not reflect the actual consumption of heat energy of each residential building. Furthermore, so far tenants who live in buildings with high consumption had no incentive to improve the energy efficiency of their building. Due to the lump sum principle, no one is stimulated to rationally use expensive energy, neither plants nor consumers.

According to the Law on energy in Serbia, the Law on efficient use of energy and the Decision on the heat supply in the city of Belgrade, PUC “Beogradske elektrane” is obliged to install measuring devices for payment per kWh of energy supplied, regarding fairer distribution of payment costs and rational energy management as well as increase energy efficiency of the buildings. Generation plants are required to switch to reading the central heat meters (located in the substations) and to calculate consumption of heat energy of each building individually.

This paper considers measures to improving the District Heating System (DHS) in Belgrade in order to perceive the reduction of heating energy consumption and environmental pollution. Two case studies are presented as comparative analysis of future costs of central heating for apartments - one in a building from 70-s without insulation and proper windows and another one built recently at the same area in Belgrade.

Introduction

A survey of low-carbon cities worldwide is presented in the new Report from UNEP - United Nations Environmental Program in order to identify the essential factors for their success in increasing energy efficiency and use of renewable energy sources, as well as achieving the goals of zero or low greenhouse gas emissions. District energy systems (DES) emerged as best practice approach for providing a local, affordable and sustainable energy supply, improve energy efficiency and support energy access efforts. The Report represented a significant opportunity for countries and cities around the world to move towards climate-resilient, resource-efficient and low-carbon pathways (UNEP, 2015).

District Heating System (DHS) started in Serbia since 1965, when the Public Utility Company “Beogradske elektrane” was established. This company is the biggest high-quality DHS in Serbia. It provides the regular supply of heat to all consumers of DHS in the city of Belgrade.

District heating supply exists in 55 towns in Serbia (Bozic V. S., et al., 2015). In Belgrade 50% of apartments and houses are covered with it (http://www.energyobserver.com/vesti.php?lang=1&id=34732). To reduce pollution, in the last 30 years in Belgrade were closed more than 1,035 local
boiler stations running on coal and hard fuel oil, of which 174 were in the competence of the PUC "Beogradske elektrane", according to data from PUC "BE". The same data indicates that today the average annual consumption of natural gas is 85%, while seven local boiler stations are using biomass briquettes and 2 boiler stations are using biomass pellets saving 4,500 t CO₂ per year. It proved the importance of DHS modernization and the transition from consumption of fossil fuels to energy sources that do not pollute the environment, in other words the transition to low CO₂ technologies. Such activities have already been undertaken by PUC "Beogradske elektrane", of which expected positive effects on the regional level. These activities are mentioned in the paper.

Currently, in Serbia the heating rate is not calculated according the actual consumption of heating energy, but according to specific consumption of Qh = 140 kW/h per square meter per year, although the average specific consumption of buildings primarily depends on the insulation and exterior joinery, i.e. heat losses. According to the Law on energy in Serbia, the Law on efficient use of energy and the Decision on the heat supply in the city of Belgrade, PUC "Beogradske elektrane" is obliged to install measuring device for payment per kWh of heat energy supplied, regarding fairer distribution of payment costs and rational energy management as well as increase energy efficiency of the buildings. This is necessary to achieve the trends of developed countries in terms of calculation of energy consumption for heating and to generate a responsible attitude of the society towards energy consumption. In this sense, the paper presents a comparative analysis of two examples of residential buildings in Belgrade, with different facade thermal performance, systems of calculation and billing of energy consumption.

The biggest challenge for Balcanic countries regarding district heating policy, is the fact that the tariff revenue does not cover the full costs of district heating. This is the main factor for poor maintenance of the heating system, big losses, inefficiency and slow process of modernization. On the other hand, both low tariffs and non-payments also reduce incentives for consumers to save (Roshchanka, Evans, 2012).

In this paper the methodological approach includes the following steps:

- Review of procedures and measures for improvement of DHS in Serbia and city of Belgrade.
- Consideration of methods for measurement of supplied heat energy to the buildings and collection; Analysis and discussion of case studies.
- Comparative analysis of case studies.

The aim of the paper is to show the activities performed by DHS in Serbia and Belgrade due to reduce the consumption of fossil fuels for heating and thus environmental pollution at the regional level.

The existing infrastructure of district heating in Serbia and Belgrade, and measures of improvement

The DHS in Serbia has not been modernised. Waste heat is not utilized in DHS nor is renewable energy. Heat production in DHS in Serbia is solely based on fossil fuels, mostly high quality imported fuel such as natural gas. Heat is produced in large scale boilers designed to deliver optimal heat to most distant consumers in the coldest days (http://serbia-energy.eu).

The total number of dwellings in Serbia is 2,423,208, of which 2,380,810 with private ownership and 41,068 with other types of ownership, according the Census from 2011 (Book 25, 2013). The number of apartments with district heating installation is 535,456, which represents 22.1% of the total, while the number of apartments without district heating installation is 77.8% of which is 20.6% with central heating and 57.2% without district and central heating, as shown in Chart 1 (Book 30, 2013; http://www.vilibila.rs/srpski/izvestaj/0508/Popis%20stanovnistva%202011%20stanovi%20prema%20vrsti%20grejanja.pdf). According to the data received from PUC "Beogradske elektrane" at the end of
2015, all the heating plants in Serbia are supplying around 700,000 apartments (25% of all apartments in Serbia).

![Figure 1 - Occupied dwellings according to the type of heating in the Republic of Serbia, (Book 30, 2013).](image)

According to the data measured in substations and received from PUC "Beogradske elektrane", the surface of apartments with district heating installation is around 45,000,000 m\(^2\). Measurements in the substations throughout Serbia show that the annual energy consumption for heating is in the range of 130-200 kWh/ m\(^2\).

It is obvious that a large number of apartments are individually heated using coal, wood and electricity as energy sources, which points to significant carbon emissions. The number of dwellings for which heating is used another type of energy, for example solar, geothermal energy, wind energy, etc., in the Republic of Serbia is very small. To Census data, this kind of energy for heating is used in only 16,706 flats. Most of these apartments are in the region of Vojvodina (http://www.vibilia.rs/srpski/izvestaj/0508/Popis%20stanovnistva%202011%20stanovi%20prema%20vrsti%20grejanja.pdf).

Municipal DHS in Serbia operate in 55 cities and towns with the installed capacity of around 6,800 MJ/s (thereof 3,000 MJ/s in Belgrade, which is about 44%), and total heat production of 7,000 GWh (Indicators of District Heating in Heating Plants which are Members of Business Association “Heating Plants of Serbia” (in Serbian), Association of Serbian Heating Plants, Belgrade, 2010). Approximately 22.1-25% of Serbian households are connected to the district heating system. The district heating systems are fueled by natural gas (65%), heavy and light fuel oil (18%), electricity (2%), and coal (15%). (Bozic V. S., et al., 2015). Structure of fuel consumption per generation plants in Serbia is presented in Table 1. Liquid fuel and natural gas make up about 80% of total consumption in generation plants in Serbia.

**Table 1 - Structure of fuel consumption per generation plants in Serbia.**

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>65%</td>
</tr>
<tr>
<td>Heavy and light fuel oil</td>
<td>18%</td>
</tr>
<tr>
<td>Electricity</td>
<td>2%</td>
</tr>
<tr>
<td>Coal</td>
<td>15%</td>
</tr>
</tbody>
</table>

When it comes to the implementation of organized and efficient measures to reduce energy consumption and environmental pollution, then the improvement of infrastructure of district heating is the procedure that is government supported and in a short time can make improvements at the regional level.

In Belgrade power plants average annual consumption and percentage of certain fuels in PUC "Beogradske elektrane" is as follows:
• app. 350 million cubic meters of natural gas (85%),
• app. 46,000 tons of heavy fuel oil (13.5%),
• app. 3,200 tons of coal (0.4%),
• app. 2,000 tons of pellets (biomass – 0.25%),
• app. 1,500 tons of briquettes (biomass – 0.2%),
• app. 500,000 liters of heating oil (0.1%).

Share of gas and heavy fuel oil in total planned fuel consumption changes depending on the price of these fuels. Fuel consumption is planned on the basis of average energy consumption of 140kWh/m² per year (http://serbia-energy.eu/belgrade-district-heating-development-a-modernization-strategy-overview/).

The PUC "Beogradske elektrane" has conducted the following measures in order to reduce environmental pollution and start the transition to renewable energy sources:

• In the last 30 years this company closed more than 1,035 local boiler stations (on coal and hard fuel oil). Existing customers are connected to the large heat sources.
• During heating season 2007/2008, "Beogradske elektrane" run big plants on pellets and briquettes.

The company’s commitment towards the introduction of renewable energy sources can be identified through running big plants on pellets and briquettes: 7 local boiler stations are using biomass briquettes; 2 boiler stations are using biomass pellets (Fig. 2); total installed capacity is 24 MW (using biomass). Average consumption per heating seasons is 2,000 tons of pellets and 2,000 tons of briquettes. Thus reduction of CO₂ emissions in the amount of 4,500 tons per year is achieved.

Figure 2 - Pellets (biomass) as a fuel in a local boiler station “Simiceva” of PUC “Beogradske elektrane” in Belgrade.

Savings are achieved by increasing in operation efficiency of the PUC “Beogradske elektrane”, which is shown in Table 2.
Table 2 - Increase in operation efficiency of PUC "Beogradske elektrane".

<table>
<thead>
<tr>
<th>Year</th>
<th>2001</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed power</td>
<td>2.700MW</td>
<td>3.000MW</td>
</tr>
<tr>
<td>Generation plant efficiency</td>
<td>0.78</td>
<td>0.88-0.96 (new boiler)</td>
</tr>
<tr>
<td>End user specific energy consumption</td>
<td>150KWh/m²</td>
<td>109KWh/m²</td>
</tr>
</tbody>
</table>

Measures to improve the district heating in Belgrade are planned through the high level of the plant automation as the basic objective and through the high level of substations automation as additional objective, taking into account lower operation and investment costs as final objective (Fig. 3). Also, SCADA and TERMIS modules are implemented in order to create connections for further DHS in Belgrade and optimize the system.

Figure 3 - District heating system improvement in Belgrade.

Serbia ranks among the 20 most energy intensive and among the 10 most carbon intensive countries in the world in terms of GDP (Climate Change Aspects of Energy Sector Development in Serbia, 2012). GHG emissions of Serbian energy sector are estimated at 31 million t CO₂ eq. (year 2010, without Kosovo), which is about 45% of Serbia’s total CO₂ emissions and it is expected that the emissions of greenhouse gases will increase by about 10-13% by the year 2020 comparing to 2010, as a result of increased demand for electricity (Bozic et al., 2015). In Serbia, due to outdated energy production and distribution facilities, there is a great potential for energy efficiency and reduction of operational losses and emissions of greenhouse gases. Through improvement using new technologies and increase of existing Thermal Power Plants (TPP) capacity, as well as closing some old TPP which operate with low efficiency, significant reduction of CO₂ emissions could be achieved. Additional decrease of CO₂ emissions could be achieved by retrofitting of existing buildings by putting thermal insulation, replacement of windows, replacement of existing lighting systems with more efficient ones, as well as by glazing the balconies and loggias. Total mitigation potential in energy and building sector is estimated at 12.5 Mt CO₂ eq./year (Assessment of the Projects' Potential in the Field of Renewable Energy Sources, Energy Efficiency and Framework of Clean Development Mechanism Foreseen by the Kyoto Protocol in the Republic of Serbia, 2007).
Measurement of supplied heat energy to the buildings and collection/billing

The current method of payment for heating of residential space in Belgrade is lump billing method. Lump billing method is a collection for heating per square meter of residential space. Such billing method does not reflect the actual consumption of heat energy of each residential building. The heating rate is calculated according to specific consumption of $Q_h = 140 \text{ kW}/\text{h per square meter per year}$.

The zones of Belgrade covered with district heating system PUC “Beogradske elektrane” are presented in Figure 4.

![BELGRADE heating areas](image)

**Figure 4 - Zones of Belgrade covered with district heating system PUC “Beogradske elektrane”.

The average specific consumption of buildings primarily depends on the insulation and exterior joinery, i.e. heat losses. Depending on the thermal performance of building envelope, buildings have different energy consumption for heating, but that the current method of payment does not take into account. It has the following negative effects:

- Customers who live in buildings that consume less energy than the average ($Q_h = 140 \text{ kW}/\text{h per square meter per year}$), now pay more for heating annually.
- Customers who live in buildings with high consumption until now had no incentive to improve the energy efficiency of their building.
- Because of the payment according to the lump sum, no one is stimulated to rationally use expensive energy, neither plants nor consumers.
In order to ensure proper accounting of consumed thermal energy, the following legal obligations of generation plants in Serbia are introduced:

- According to the Law on energy in Serbia, the Law on efficient use of energy and the Decision on the heat supply in the city of Belgrade, PUC "Beogradske elektrane" is obliged to "install measuring device for supplied heat energy which provide accurate information on the actually supplied amount of heat, as well as the exact time of supply of heat energy to the building".

- Generation plants are required to switch to reading of the central heat meters (located in the substation) and to calculate consumption of heat energy of each building individually.

- Consumption of heat energy of the building is distributed per apartments according to their heating surface (m² of apartment).

In order to meet legal obligations in 2004 the PUC "Beogradske elektrane" has started modernization of district heating in Belgrade (more than 8.500 substations - located in residential buildings). Modern measuring and control equipment are installed in a few substations that enable rational heat supply and measurement of building heat energy consumption.

According to the "Law on the efficient use of energy", customers in Serbia shall hire companies that are on the market, at their own expense, in order to:

- Install thermo-regulatory valves on each radiator (for consumption management);

- Install heat cost allocators or heat meters (depending on the internal installation) - for the allocation of consumption of each flat.

Companies that are on the market can install equipment and carry out the allocation of heat energy that is delivered to the building. By installing this equipment, consumption can be managed by each user in order to economize and reduce the cost.

Transition to collection according to consumption of building and/or apartment does not necessarily mean that heating bills will be lower. It depends on the consumption of heat energy of building / apartment (insulation, windows, as well as customer’s needs for heat energy).

Analyses and discussion of case studies

Two case studies will be presented in terms of calculating the costs of central heating for apartments - one in a building from the ‘70s without insulation and proper windows and another one built recently at the same area in Belgrade.

The first example refers to the building in the Block 45 in New Belgrade. The building was built in 1972 (Fig. 5). Facade of the building has no thermal insulation. The measured specific energy consumption is Qh=184 kWh/m² per year.
The residents currently pay (e.g. apartment of 50 m²) 114 RSD/ m² (current price) x 50 (floor area) x 12 (months) = 68,400 RSD per year.

When customers pay according to measured consumption, the following items are taken into account:

- The fixed part - input power – 24,522.5 RSD per year/12 months = 2,043.5 RSD per month.
- Consumed energy (kWh) – 62,744 RSD per year.
- The total amount – 87,266.5 RSD per year.

The second example relates to the building in the Block 70 in New Belgrade. The building was built in 1994 (Fig. 6). Facade thermal insulation has a thickness of 5 cm of mineral wool. The measured specific energy consumption of the building is Qh=122 KWh/m² per year.
Payment based on the measured consumption means that each customer will receive an invoice for part of the consumed heat of the concrete building, according to the heating surface of his apartment. Invoice will include fixed and variable costs. Like invoice for the electricity, the invoice will include: engaged power and consumed kWh.

The engaged power represents a fixed cost of the energy company that is paid as lump sum, but in the current invoice it is not separately shown, so the customer can not notice it. Fixed costs are very severely restricted by legislation. These are justified costs approved by regulations.

Consumed kilowatt hours (kWh) of heat energy are variable costs, costs relating to energy costs (gas, fuel oil, coal, biomass, fuel oils). City of Belgrade, by the "Decision on the heat supply in the city of Belgrade", respecting international standards (derived from the German standard DIN) in the field of technical conditions for designing residential buildings, in Article 45 of the Decision, has prescribed achieving and maintaining an internal temperature in the room of tariff customers of 20 (± 1) ° C, in order to achieve the required conditions of comfort. In this way, it is possible to ensure rational use of primary energy. Procedure of calculation includes the following:

- Consumed kWh are recorded by central heat meter located in the substation of the building.
- Total consumption of the building is distributed on the heated area of the apartments.
- The current price of kWh of heat energy with VAT is 8.39 RSD since 30.09.2015.

**Table 3 - A comparison of case studies.**

<table>
<thead>
<tr>
<th>Year of construction</th>
<th>1972</th>
<th>1994</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case studies in New Belgrade</td>
<td>Nehruova 178, Block 45</td>
<td>Jurija Gagarina 31v, Block 70</td>
</tr>
<tr>
<td>Floor area 50m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>Energy consumption</td>
<td>184 kWh/m²·year</td>
</tr>
<tr>
<td>Billing</td>
<td>114RSDx50m²x12months</td>
<td></td>
</tr>
<tr>
<td>Total amount</td>
<td>68,400RSD per year</td>
<td></td>
</tr>
<tr>
<td>Consumption-based billings</td>
<td>Fixed part</td>
<td>24,522.5RSD per year</td>
</tr>
<tr>
<td>Consumed energy</td>
<td>62,744.0RSD per year</td>
<td>41,602.0RSD per year</td>
</tr>
<tr>
<td>Total amount</td>
<td>87,266.5RSD per year</td>
<td>66,124.5RSD per year</td>
</tr>
</tbody>
</table>

A comparative analysis of two case studies shows that a significant increase in the amount to be paid can be noticed in the case of building without thermal insulation, while a small reduction in the amount to be paid is present in the case of buildings with poor thermal insulation thickness (in this case 5 cm).

Generally, it can be concluded that excessive consumption of energy is present in households, mostly as a result of the construction of energy irrational buildings. Removing these irrationalities, may represent the largest energy resource in Serbia in the next 5 - 10 years. In this sense, it is necessary to recover the building stock in terms of improving energy performance. Incentive for the building reconstruction could be caused by the implementation of payment based on the measured consumption, payment per kWh of heat energy supplied, and a short payback period of investment.

According to the data received from PUC "Beogradske elektrane", in terms of measures taken to reduce energy consumption for heating should be noted that it is fully completed pilot project of installation of thermostatic radiator valves and heat cost allocators to 135 apartments in New Belgrade’s Block 34. For consumers that are covered by this pilot project the consumption of thermal energy is reduced by 15 %. This means that consumers, in accordance with their needs, regulate the temperature in their own apartments and thus rationalize consumption. In addition, electricity consumption in modernized substations is lower by as much as 40 %. Also, training on software for the calculation and payment according to the consumption of thermal energy is carried out.
Conclusion

DHS in Serbia plays an important role in meeting basic heating needs and faces serious challenges that must be resolved regarding economical sustainability. Building level heat metering, coupled with technical solutions to improve efficiency of heat delivery to households, would provide mutual benefits for customers, district heating companies, and the Government. Heat metering and consumption-based billings are important steps towards improving the financial sustainability of the District Heating sector.

The measures for improving of District Heating System in Belgrade are presented in the paper. The proposed changes towards consumption based billing for heating should have the effect of increasing citizens' awareness regarding saving the energy and providing more sustainable buildings (according the energy consumption). District heating system in Serbia plays an important role in meeting basic heating needs and faces serious challenges that must be resolved regarding economical sustainability. Heat metering and consumption-based billings are critical steps on the path to sector reform. Building level heat metering, followed with technical solutions to improve efficiency of heat delivery to households, would provide mutual benefits for customers, District Heating companies, and the Government. The Government can play an important role by promotion of heat metering and consumption-based billing as well as by improving the financial sustainability and affordability of DH services and financing energy efficiency improvements. Furthermore, retrofitting of existing buildings (by adding the insulation, changing the windows, glazing balconies) would decrease CO₂ emission.

District heating policy should be examined in the broader context. Based on the experience in Eastern Europe, the success of district heating reforms relies largely on coordination and sequencing with other policies and sectors, such as energy, economic performance, and social policy (Roshchanka, Evans, 2012; Lampietti, J. A., Meyer, 2002).

In order to meet EU legislatives it is necessary to apply metering in district heating system (Semikolenova, Pierce, Hankinson, 2012). District heating system in Serbia, like in other Eastern European countries, was a social welfare for final consumers rather than a commercial activity. During the transition period the politicians have been afraid about increasing heating bills. Many consumers still believe that district heating is a social welfare and that it should still be provided with a lower price for everyone. Political support is necessary for applying metering in Serbia.

Prioritising the technological modernisation of energy facilities and installations to reduce emissions from generation plants aims not only to a significant increase in the heating production capacity of a large part of existing plants, but also to a reduced threat to the environment. Increasing energy efficiency and the use of renewable energy resources by 2020 that directly contribute to greenhouse gasses emissions reduction are main priorities for DHS in Serbia.

Acknowledgments

This work has resulted from research within the COST Action TU1104 "Smart Energy Regions" and scientific project: "Spatial, Environmental, Energy and Social Aspects of Developing Settlements and Climate Change – Mutual Impacts" (TP36035), financed within the program Technological Development by the Ministry of Education and Science of the Republic of Serbia.

References


Decision on the heat supply in the city of Belgrade, 2007.

Indicators of District Heating in Heating Plants which are Members of Business Association “Heating Plants of Serbia” (in Serbian), Association of Serbian Heating Plants, Belgrade, 2010.


Evaluation of a regional scale retrofit programme to upgrade existing housing stock to reduce fuel poverty, reduce carbon emissions and support the supply chain

Jo Patterson

Welsh School of Architecture, Cardiff University, Bute Building, King Edward VII Avenue, Cardiff, CF10 3NB. Email: patterson@cardiff.ac.uk

Abstract: In 2007 the EU committed to move Europe to a low carbon economy and it was agreed that carbon dioxide (CO₂) emissions would be cut by at least 20% of 1990 levels by 2020 (European Commission, 2008). Following this the UK Climate Change Act 2008 (DECC, 2008) set a target of 80% reductions on 1990 baseline UK CO₂ emissions levels by 2050. These legislative interventions need to be accompanied by significant changes to all sectors of the built environment at scale to enable the targets to be met. Retrofitting existing buildings is critical to making these cuts as 80% of buildings currently in existence will still be present in 2050.

This paper will present an evaluation of a £9.6 million regional scale retrofit programme funded under the Welsh Governments Arbed 1 Programme which aimed to reduce fuel poverty, reduce carbon emissions and support the energy efficiency and renewable supply chain and encourage recruitment and training in the sector. Results have been obtained from a desk top data collection and energy calculations based on property types and ages.

The evaluation work presents the environmental, social and economic impacts of the programme and demonstrate the lessons learnt to help improve the implementation of the other regional retrofit projects providing evidence of the impacts of a large scale retrofit programme that are necessary for the deep carbon reductions required in the near future.

Keywords: Regional, retrofit, energy efficiency, Wales.

Introduction

In 2007 the EU committed to transform Europe into a highly energy efficient, low carbon economy (European Commission, 2008) and EU Governments agreed that emissions would be cut by at least 20% of 1990 levels by 2020. Significant changes need to be made to all sectors of the built environment in order for these targets to be met, through increasing efficiency in energy demand and providing energy supply from low carbon sources and storing energy where possible. 29% of total final energy consumption in the UK is used in housing, the highest of all sectors (Palmer and Cooper, 2013). Traditional barriers for the necessary changes to be made include a lack of funds available to householders and government, knowledge regarding appropriate changes for housing type and the cost of ‘deep’ retrofit where clear financial savings can be made on energy bills (Jones, 2013; Baeli, 2013).

Figure 1 summarises the energy consumption of a typical home in the UK in 2009 and highlights the opportunities to save energy through space and water heating (78% of energy consumption). Changes are therefore required in both lifestyle and the current housing stock in order for these difficult targets to be met.
Figure 1 – Energy consumption in a typical home in the UK (DTI, 2009).

There are a broad range of retrofit options available that should be tailored to the characteristics of the building stock. Low carbon retrofit measures can be combined to reduce demand through fabric and form improvements such as increased insulation, installation of energy efficient appliances and layout, through electrical and thermal energy storage and through generating energy from renewable energy sources. Registered Social Landlords (RSLs) in the UK own 1,000s of different types of properties which are situated in different locations with different types of resident. Identifying the most appropriate retrofit solution can be extremely complex. For example, taking the ‘whole house’ approach on fewer dwellings or implementing one or two measures over a wider range of stock. This decision is often influenced by the type of grant funding available and the approach of the RSLs. A key driver for social housing improvements in Wales is the Welsh Quality Housing Standard (WHQS) (Welsh Assembly Government, 2008) which encourages physical standards and condition of existing housing and that all social housing should reach a SAP of 65 as an indication of ‘adequate fuel efficiency and insulation’. The WHQS is supported by a range of funding streams/grants have been made available to reduce emissions from the domestic housing stock in the UK. Energy suppliers have been involved through Carbon Emissions Reduction Target (CERT) and Community Energy Saving Programme (CESP) which were followed by Energy Company Obligation mainly set up to target appropriate measures to households likely to need additional support. The UK Government have promoted a series of new initiatives through the Energy Act 2012 (DECC, 2013) to encourage the uptake of energy efficiency measures and low carbon technologies including the Green Deal, Feed In Tariff, Renewable Heat Premium Payment and Renewable Heat Incentive. The Welsh Government have established Nest and the New Fuel Poverty Scheme set by the Welsh Assembly Government in 2010 (Welsh Assembly Government, 2010).

In 2009 over 5.5 million (approximately 21%) households in the UK were living in fuel poverty, spending more than 10% of their household income on heating (DECC, 2011). In Wales it was estimated that 332,000 or 26% of all households were suffering from fuel poverty in 2008, an increase from 134,000 in 2004 with 44% of these households living in social housing (Welsh Government, 2012). The price of domestic gas and electricity has been relatively stable between 2010-2015 after increasing steadily through 2000-2008 (Dempsey, Barton and Hough, 2016). As household incomes have generally fallen or levelled off since the economic downturn in 2008, the main way to reduce the impact of future price rises is to increase energy efficiency of homes and provide energy from renewable energy sources.

If the domestic building stock is to be made more sustainable and if CO₂ targets are to be realised, then the problem of how to improve the existing built environment must be addressed (European Union, 2002). With a replenishment rate of just 1% per annum (DCLG, 2006) with over 20 million existing homes in the UK (Utley and Shorrock, 2012), good quality retrofitting is essential to reach targets.
The retrofit programme

Arbed 1 was set up to take a ‘whole house’ approach to install energy efficiency measures and renewables across Wales. It is the Welsh Governments (WG) Strategic Energy Performance Investment Programme. The scheme included properties owned by Registered Social Landlords (RSLs), Local Authorities (LAs) and owner occupied homes. The strategic objectives of the Arbed 1 Scheme were to:

- reduce fuel poverty;
- reduce carbon emissions;
- support the energy efficiency and renewables supply chain and encourage recruitment and training in the sector.

Properties were targeted in Strategic Regeneration Areas within Wales which were also believed to have low household incomes. Arbed 1 was established in 2009 and 28 separate projects involving more than 6,000 homes including both public and private housing with an investment of £60 million. Arbed 2 took place between 2012 and 2015 with the same objectives as Arbed 1 with £45 million to improve energy efficiency in Welsh homes targeting solid wall, off gas properties in low income areas with a more even split of public/private households.

Warm Wales, a Community Interest Company, based in Port Talbot in South Wales was commissioned by five Registered Social Landlords (RSLs) and two Local Authorities (LAs) to help deliver their Arbed 1 projects. Warm Wales’ undertook scheme design, project management and provide design advice working alongside contractors, RSLs/LAs and energy suppliers. Funds were accessed from CERT and CESP together with gas fuel-switch grants via the energy supplier Wales & the West Utilities maximising the benefits for the communities involved. The 7 projects were part of the 28 projects funded by the WG. Each RSL/LA had made the decision as to what properties to improve and what measures to implement during the application process to WG. A total of £9.6million was invested within the Warm Wales programme. The total number of properties included within the Warm Wales Programme was 1,147.

The seven projects are summarised in Table 1.
Table 1 - Key characteristics of each of the Warm Wales Arbed 1 projects.

<table>
<thead>
<tr>
<th>RSLs/local authorities</th>
<th>Location</th>
<th>Total no. of units managed by RSL</th>
<th>Main type of properties included in Arbed grant</th>
<th>Arbed grant</th>
<th>Main measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charter Housing (incl part Caerphilly CBC homes)</td>
<td>South East Wales – Newport area</td>
<td>5,500</td>
<td>2 and 3 bed terrace built pre 1919 by National Coal Board</td>
<td>£1.6 million</td>
<td>EWI, Solar PV</td>
</tr>
<tr>
<td>Melin Homes</td>
<td>South East Wales – Pontypool area</td>
<td>3,000</td>
<td>1/3 pre 1919 solid wall, 2/3 post 1980 cavity wall houses</td>
<td>£1.0 million</td>
<td>EWI, Solar PV ASHP</td>
</tr>
<tr>
<td>Family Housing</td>
<td>South Wales area – Swansea area</td>
<td>2,300</td>
<td>Pre 1919 solid wall</td>
<td>£1.0 million</td>
<td>EWI, Solar PV</td>
</tr>
<tr>
<td>Coastal Housing</td>
<td>South Wales – Swansea area</td>
<td>5,500</td>
<td>½ pre1919 solid wall, ½ post 1980 cavity wall</td>
<td>£1.3 million</td>
<td>EWI, Solar PV</td>
</tr>
<tr>
<td>City and County of Swansea</td>
<td>South Wales – Swansea area</td>
<td>Over 13,000</td>
<td>Post war semi detached housing and some 1980s terraced</td>
<td>£2.5 million</td>
<td>EWI, Fuel switching, Solar PV Solar thermal</td>
</tr>
<tr>
<td>Tai Ceredigion</td>
<td>Mid West Wales – Aberystwyth area</td>
<td>2,200</td>
<td>Flats and semi det houses built between 1965-1980</td>
<td>£600,000</td>
<td>EWI, Fuel switching</td>
</tr>
</tbody>
</table>

Properties and measures

Fabric improvements involved the implementation of external wall insulation (EWI) to improve the internal thermal conditions. Solar PV, fuel switching, solar thermal and air source heat pumps were installed to provide a more efficient energy supply system. A total of 1,391 measures have were installed as part of the Warm Wales Arbed 1 Programme. 905 properties received 1 measure, 240 received two measures and 2 properties received three measures. This illustrates that although Arbed 1 aimed to take a whole house approach, the projects within the Warm Wales Programme took more of a blanket approach improving a greater number of properties with fewer measures.

Figure 2 illustrates the types of measures installed within different aged properties. EWI was targeted towards solid wall properties as this was believed to have the highest improvement in emissions and comfort in this type of housing. Fuel switching was predominant in both the 1945-1964 and 1965-1980 age bands. This is likely to be the case as these properties are remotely located and densely grouped in estates making fuel switching a relatively straightforward option with the funding available.
Figure 2 – Measures installed in different aged properties.

Solar PV was the most common measure within the post 1980s properties. ASHP were only applied to properties in the 1965-1980 and post 1980 age groups, these were applied to flats on both occasions as illustrated in Figure 3.

Figure 3 – Measures installed in different types of property.

Environmental outcomes

One of the main objectives of Arbed 1 was to reduce carbon emissions to assist in meeting the targets set by Welsh and UK Government. CO\textsubscript{2} savings and SAP improvements have been calculated using information regarding the measures implemented and the types of properties applied to on a property by property basis using the Energy and Environmental Prediction (EEP) Model (Jones et al, 2000 and Jones et al, 2007) using ‘as built’ U-values of the different aged properties and fabric (BRE, 2009). Properties within the EEP model are clustered using property age, heated ground floor area (m\textsuperscript{2}), façade (m\textsuperscript{2}), window to wall ratio and exposed end area (m\textsuperscript{2}). For each of the types of property, SAP calculations before and after have been made together with CO\textsubscript{2} savings. All calculations have been made using the SAP calculator based on the BRE SAP Procedure 2009. Modelling results have been compared to actual energy consumption and results have proved reliable when considering large
number of properties (Iorwerth, et al., 2013). These calculations are based on the database of property plans provided to Warm Wales by each of the RSLs/LAs which included data on property age, type and other property based information. There were however, inconsistencies and gaps in this dataset, particularly regarding age of properties. Where gaps were present, information has been obtained using digital maps including Google map. This has enabled SAP ratings, CO₂ emissions and energy saving calculations to be made to demonstrate the improvements as a result of the Warm Wales programme. Gas has been assumed to the primary fuel apart from properties where fuel switching or ASHP have been installed where electrical heating was assumed to be the original heating fuel.

The average SAP rating before works across the properties was 60 and ranged from 43 to 66. Most properties were below the WHQS recommended SAP of 65 (Welsh Assembly Government, 2008). The target set by the WHQS is very ambitious as the average SAP rating for a British home is 51.6 (Palmer and Cooper, 2011). Figure 4 illustrates SAP ratings before and after the measures were installed. The average SAP rating following the works was 69, with a range from 58 to 82 with only 231 properties falling below the WHQS of 65.

![Figure 4 - SAP ratings of properties before and after measures were installed.](image)

Total CO₂ savings for the Warm Wales Programme have been calculated at 3,025 tonnes per year. More than 30% of the properties saved more than 3,000 kg/yr CO₂ as illustrated in Figure 5.

![Figure 5 – CO₂ savings per property kg/year.](image)
Results illustrate that properties with the highest CO$_2$ savings are those which have undergone fuel switching and are relatively large in floor area. Large CO$_2$ savings are associated with the change from electricity (Economy 7) to gas as the main heating fuel as a lower emission factor is associated with gas compared to other heating fuel sources as illustrated in Table 2.

**Table 2 – CO$_2$ emissions for different heating fuels (Carbon Trust, 2011).**

<table>
<thead>
<tr>
<th>Heating fuel source</th>
<th>kgCO$_2$/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>0.19</td>
</tr>
<tr>
<td>Coal</td>
<td>0.33</td>
</tr>
<tr>
<td>Oil</td>
<td>0.28</td>
</tr>
<tr>
<td>Electricity from grid</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Arbed 1 has made a significant improvement to the aesthetics of communities, particularly those that have had EWI installed (Figures 6).

![Figure 6 - Aesthetic improvement of housing.](image)

**Social outcomes**

Training requirements were set as part of the funding criteria for Arbed 1. 156 training weeks were required to be attended per £1 million investment. Training opportunities provided as a result of the Warm Wales Programme included initiatives such as ‘Job Match’, a Welsh Government, Department for Work and Pensions and local authority backed initiative offering support to help people to overcome barriers to employment and ‘Beyond Bricks and Mortar’ were used to recruit staff. The majority of trainee and apprenticeship opportunities were provided via the subcontractors and ranged from short term trainee positions to 3 and 4 year apprenticeships. Overall training weeks exceeded the target by over 25%.

Fifteen Community Energy Wardens were employed by Warm Wales to work with to support community engagement, installation of measures and provide an aftercare service to residents. This
supporting role included being on hand to discuss and support residents in the understanding of information related to the programme, benefits of individual measures and potential impacts throughout the installation process. The Energy Wardens were trained and supported to deliver Home Energy Assessments, basic energy advice and installation of Real Time Displays. All fifteen received significant training and work experience to improve their long-term work prospects.

**Economic outcomes**

Arbed 1 sought to stimulate economic regeneration, create employment opportunities in local areas, whilst also increasing capacity in the manufacture of low carbon technologies in Wales. Warm Wales aimed to target all grant assistance available to bring maximum benefit to low household income areas. The total cost of the works implemented through the Warm Wales Programme was £9,658,509. The breakdown of this is illustrated in Table 3.

**Table 3 – Funding allocation through Warm Wales Programme.**

<table>
<thead>
<tr>
<th>Funding allocation</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm Wales Programme - RSL/LA properties</td>
<td>£6,372,155</td>
</tr>
<tr>
<td>Leveraged measures on RSL/LA properties</td>
<td>£2,141,104</td>
</tr>
<tr>
<td>Warm Wales Programme - privately owned properties</td>
<td>£1,145,250</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>£9,658,509</strong></td>
</tr>
</tbody>
</table>

The total cost of the measures implemented to RSL/LA properties utilising Arbed 1 funding through the Warm Wales Programme was £6,372,155. £5,580,367 of this funding was provided from grant support mechanisms including Arbed/CESP/ CERT and Low Carbon Building Programme. The RSLs/LAs contributed £791,789 towards the direct cost of work undertaken to RSL/LA properties, 12.4% of the expenditure. £2,141,104 additional funding was provided to undertake leverage measures by the RSLs/LAs on their properties. This included additional works such as replacement of eaves, electrical upgrades and general making good, together with making use of facilities such as scaffolding whilst on site to reduce future disruption. £1,145,250 has been invested on EWI and new heating systems by owner occupiers.

Average actual costs per measure can be seen in Table 4. These are the average direct costs charged by the contractor to undertake the works including enabling works which varied according to the measure being installed.

**Table 4 - Actual costs per measure installed during the Warm Wales projects.**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Average cost</th>
<th>Note</th>
<th>No. of measure installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>EWI</td>
<td>£7,730</td>
<td>Inc enabling works and 5% VAT</td>
<td>648</td>
</tr>
<tr>
<td>Fuel switching</td>
<td>£3,126</td>
<td>Inc 20% VAT</td>
<td>241</td>
</tr>
<tr>
<td>Solar PV</td>
<td>£4,988</td>
<td>Inc enabling works</td>
<td>414</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>£4,393</td>
<td>Inc enabling works</td>
<td>46</td>
</tr>
</tbody>
</table>

A comparison has been made of the CO\textsubscript{2} savings made per pound spent on the different measures for a semi-detached/end terrace pre 1919 house, illustrated in Table 5. The highest CO\textsubscript{2} savings are made when fuel switching takes place, resulting in a CO\textsubscript{2} saving five times greater than the other measures for this type of property. This assumes that the original fuel source is economy 7 electrical heating which is the highest emitter of CO\textsubscript{2}, as illustrated in Table 2.
Although CO\textsubscript{2} savings associated with fuel switching are in the magnitude of those required to achieve long term targets set, opportunities for fuel switching to gas are limited. The current fuel mix for domestic energy consumption in the UK is 1% coal, 21% electricity and 69% gas (DECC, 2011), which means that only around 22% have the opportunity to make this relatively cheap but significant change. CO\textsubscript{2} savings are higher for EWI than for solar PV and solar thermal and prove to be better value for money with a lower £ per kg CO\textsubscript{2} per year.

**Table 5 - Illustration of the CO\textsubscript{2} savings made per £ spent for a semi/end terraced house.**

<table>
<thead>
<tr>
<th>Measure</th>
<th>CO\textsubscript{2} savings (kg/yr)</th>
<th>£ per measure</th>
<th>£ per kg CO\textsubscript{2} per yr</th>
<th>% CO\textsubscript{2} saving (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EWI</td>
<td>1,670</td>
<td>£7,730</td>
<td>£4.63</td>
<td>25</td>
</tr>
<tr>
<td>Fuel switching</td>
<td>8,939</td>
<td>£3,126</td>
<td>£0.35</td>
<td>57</td>
</tr>
<tr>
<td>Solar PV</td>
<td>751</td>
<td>£4,988</td>
<td>£6.64</td>
<td>11</td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>395</td>
<td>£4,393</td>
<td>£11.12</td>
<td>6</td>
</tr>
</tbody>
</table>

The average annual energy bill before the works were undertaken was approximately £990. This corresponds to the estimated UK domestic fuel bill of £1,032 per year as calculated by OFGEM (2011) based on a typical consumption of 16,500 kWh per year of gas and 3,300 kWh per year of electricity. Figure 7 demonstrates the percentage savings to householders’ energy bills as a result of the works undertaken illustrating that 50% of the households could be making more than a 20% financial saving assuming behaviour remains the same following the work.

**Figure 7 - Percentage of energy bill reduction as a result of the Warm Wales Programme measures installed.**

Assuming the behaviour of the resident remained similar, the average household energy cost after the works has been calculated to be £774 therefore saving £216 per year on energy bills. The greatest energy bill savings have been calculated for a 1980s flat that has received ASHP with a saving of over 50%. 40% energy cost savings were calculated for a mid-terrace pre 1919 house that had EWI and solar PV installed, with annual energy bills potentially being reduced by over £550. It has to be acknowledged that an element of this saving could be used to increase temperatures for increased comfort rather than the householder benefitting financially.

The combined potential financial savings for all households involved in the Warm Wales Programme is £285,000 per year. The investment involved in the Warm Wales Programme of £9,658,509 equates to a payback period of 33 years for the programme. This does not take into account the added value to the properties including the energy saving measures and associated maintenance works, the improved comfort for householders, improved aesthetic value of the communities and likely increased energy costs over time.
Conclusions

The evaluation of the Warm Wales component of Arbed 1 was undertaken to provide evidence of the environmental, social and economic impacts of the Programme to demonstrate the positive and negative aspects. This will assist with improving the implementation of other large scale retrofit programmes necessary for the deep carbon reductions required in the near future. This evaluation has highlighted drivers and barriers involved in the delivery of regional scale low carbon retrofitting of housing to reduce CO₂ emissions whilst having other positive impacts such as improving health and quality of life.

Due to the short timeframe of Arbed 1 a lack of time for appropriate planning was available, particularly at the initial planning stages which would have allowed more appropriate solutions to be identified. By undertaking an accurate survey of properties as early as possible, together with validated computer based modelling would provide reassurance of appropriate and cost effective measures. This planning process should consider the long term maintenance together with fabric, form, systems and appliances in-situ. Consistent methods of data collection and storage would simplify the surveying and planning process and aid the collation of evidence through monitoring would demonstrate if improvements are making a difference allowing lessons to be learnt for future experiences. Responsibility for this should be clearly allocated so that it is undertaken in advance of works, and in sufficient detail to allow on site-works to be as efficient as possible to minimise disruption to the resident.

The cost of work need to be carefully planned to reduce levels of uncertainty and funding sources available should be utilised fully. Cost evaluation should include more emphasis on fixed and measured capital costs at the outset together with allowance for expected operational costs including enabling works, maintenance and the cost of project management.

Undertaking Arbed 1 has provided RSLs and LAs with confidence to try out new technologies and establish new relationships with local suppliers and installers. Utilising local subcontractors on can provide continuity and experience of the types of properties involved and local manufacturers can be worked with to adapt measures as required. A lack of experience and available local skills caused problems in implementation, frequently preventing works of a satisfactory standard being delivered. Rectifying detailing due to small variations in properties took time and additional funding on site which was inefficient. Detailing solutions provided by manufacturers, agreed with their approved installers at the outset, would also assist with this.

The long term view should be to aim for a whole house approach as this would provide a stock of properties that would perform as efficiently as possible, assuming the planning, design and construction of the works had been undertaken correctly and that maintenance procedures are put in place. By undertaking few measures to many properties, underlying problems may remain within properties preventing measures working efficiently.

This evaluation has demonstrated that large scale retrofit funding (in excess of 80% grant), such as Arbed, can stimulate the implementation of low carbon technologies, providing residents with economic savings together with employment opportunities and allowed risks to be taken using technologies that had not been used in the past by RSL’s /LAs. With an increase in retrofitting, costs of measures will decrease and, with energy prices expected to increase, there is more incentive for householders to invest. This would provide more consistency in employment in the sector which would support the level of skills required to undertake work at the quality necessary for savings to be realised in practice. These broader cost-benefits of such schemes need to be accounted for to support additional funding for good quality, well planned regional retrofitting schemes.

Acknowledgements

The author would like to acknowledge support from Warm Wales Ltd, a Community Interest Company, who provided data and access to organisations involved in the Programme. Also to Dr Simon Lannon
who applied the Energy and Environment Prediction (EEP) model which was funded through the Energy and Physical Science Research Council (EPSRC grants GR/K19181 and GR/L81536).

References


European Commission, 2008. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – 20 20 by 2020 - Europe's climate change opportunity.


OFGEM, 2011. Typical domestic energy consumption figures Factsheet 96. 18.01.11.


Patterson, J., 2008. Evaluation of an energy efficiency scheme to upgrade the existing domestic building stock of a local authority region (Report to Warm Wales Ltd). Cardiff: Welsh School of Architecture, Cardiff University.


Low energy renovation of neighborhoods in southern Europe – a realistic challenge or an unviable goal?

Helena Corvacho1, Fernando Brandão Alves2, Cecília Rocha2

1) CONSTRUCT Research Unit, Laboratory of Building Physics, Faculty of Engineering, University of Porto
2) CITTA - Research Centre for Territory, Transports and Environment, Faculty of Engineering, University of Porto
Corresponding author: Helena Corvacho, corvacho@fe.up.pt

Abstract: The transformation of European existing building stock towards very low energy buildings (nearly-zero energy, net-zero energy or even plus-energy buildings) requires an effective integration and full use of the local potential of renewable energy. Due to the current economic crisis investment capability in building renovation is limited and public incentives tend to decrease. Breakthrough solutions are, therefore, needed which combine affordability along the whole life cycle, reduced maintenance and high performance reliability with reduced energy use. Energy storage is also a key point to be addressed as well as intelligent energy management systems.

In this context, it seems reasonable to think that buildings should no longer be renovated individually but as part of a global energy system, where their interactions with their environment can be predicted and simulated, as well as their interactions with inhabitants, their habits and life style. The main goal of this paper is to present a discussion on low energy renovation of existing neighborhoods in Southern Europe in an integrated perspective. Making each and every existing building become a NZEB can be a hard or even impossible task. However, an integrated approach focusing on larger urban units may present some scale advantages and may constitute an opportunity to change the urban environment in a smart energy way.

Specificities of Southern European countries will be addressed. In a milder climate with warmer winters and hotter summers, special care must be taken concerning overheating risk. Furthermore, this milder climate has determined, over the years, specific habits of heating and cooling, different from the ones of the Northern part of Europe. How much heating energy will be saved by over-insulating building envelopes if people do not feel the need to heat their houses in the first place? How can the extra investment be recovered? Situations occur where an extra insulation causes an extra need for cooling energy in summer. Therefore, suitable renovation strategies at building level must be carefully defined.

Also, the monitoring of real energy use in buildings frequently shows major differences with respect to the predicted performance. This is even more significant if a set of interacting buildings is considered. Social and behavioral factors should be taken into account. The definition of realistic solutions demands the availability of realistic predictions. Mainly for Domestic Hot Water (DHW) and domestic appliances the local potential of renewable energy at neighborhood or district level should be optimized. Economic viability will also be addressed, in order to discuss the feasibility of the low energy renovation of residential buildings in Southern Europe, where the current economic crisis originates important socio-economic barriers. A case of a residential complex in Portugal will be used to illustrate the main questions in discussion.
Introduction

The building sector is one of the most significant energy consumer in EU, representing around 40% of final energy consumption and 60% of electricity consumption. In the recent years, new and more demanding regulation came into force at a national level, in each Member State, implementing the Energy Performance of Buildings Directive (EPBD) and its 2010 recast.

However, the low volume of new construction, mainly since 2008, has limited the impact of the new energy requirements. Energy efficiency measures must therefore focus on the existing building stock. Its transformation towards very low energy buildings must take into account technical, economic and social restrictions. Furthermore regulatory requirements to be applied to the renovation of existing buildings must work as an incentive rather than an obstacle for that renovation. This demands a very realistic and careful approach.

A NZEB is defined in article 2 of the EPBD recast (European Parliament 2010) as “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, including energy from renewable sources produced on-site or nearby”. This vague definition raises several justified questions: what does “a very high energy performance” mean? And “a very significant extent”? And “nearby”?

The exchange of experience regarding the already existing “high energy performance” buildings (ranging from low energy buildings to passive houses, zero-energy and zero emissions buildings and even to energy surplus houses) helped the many attempts to clarify NZEB concept and its diverse assumptions. Figure 1 shows two examples of existing high energy performance buildings.

![Fig. 1a - Solar settlement in Freiburg – Rolf Disch Solar Architecture (Garde and Donn 2014).](image1)

![Fig. 1b - Solar XXI - Net zero energy office building in Lisbon (Gonçalves et al 2012).](image2)

Pless and Torcellini (2010) present a classification for net-zero energy buildings based on the following four different definitions:

- Net-Zero Site Energy: A site NZEB produces at least as much renewable energy (RE) as it uses in a year, when accounted for at the site;
• Net-Zero Source Energy: A source NZEB produces (or purchases) at least as much RE as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to extract, process, generate, and deliver the energy to the site. To calculate a building’s total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers based on the utility’s source energy type;

• Net-Zero Energy Costs: In a cost NZEB, the amount of money the utility pays the building owner for the RE the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year;

• Net-Zero Emissions: A net-zero emissions building produces (or purchases) enough emissions-free RE to offset emissions from all energy used in the building annually. To calculate a building’s total emissions, imported and exported energy is multiplied by the appropriate emission multipliers based on the utility’s emissions and on-site generation emissions (if there are any).

The extension of NZEB boundaries leads to the idea of a Net Zero Energy Community (NZEC) (Carlisle et al 2009).

“As the concept of NZEBs becomes technically feasible, extending its boundary to groups of buildings, campuses, communities, towns, bases, or cities becomes possible. […] For a large organization or a neighborhood, it is often more cost effective and efficient to generate RE in a central location on the campus or in the community, rather than on (or in addition to) each building. Community-scale systems allow for a single point for all maintenance and offer economies of scale—larger, central systems can be better optimized and cost less per kilowatt of generation capacity”, (Pless and Torcellini 2010).

“Applying the net zero energy concept at urban scale can provide opportunities for seasonal storage, implementation of smart grids for power sharing between housing units, controlling peak electricity production timing and reducing utility peak demand. Additional advantages of net zero energy neighborhoods include enabling design flexibility and increasing available surface areas for the integration of photovoltaic systems”, (Hachem-Vermette et al 2015).

Figure 2 shows an example of installation of PV modules in a parking lot providing energy to the nearby buildings.
The Mediterranean climate

In Southern European countries the climate is classified as Mediterranean (either Csa or Csb).

The regions with a Mediterranean climate have normally relatively mild winters and quite warm summers. However winter and summer temperatures can vary greatly between different regions. Temperatures of the Mediterranean climate zone are influenced by the geomorphology of the regions. In the West zone, closer to the Atlantic Ocean, temperatures are affected by sea breezes and are moderate during most of the year. In the east, temperatures are influenced by the climate of central Europe and Africa and are, comparatively to the western part, hotter in summer and colder in winter. Some examples of those variations are given below.

In winter, Lisbon experiences very mild temperatures, without frost or snow (mean temperature of 11.6 °C, in January, the coldest month), whereas Madrid has colder winters with annual frosts and snowfall (a mean temperature of 5.5 °C, in January). In summer, Athens experiences very high temperatures, with a mean temperature of 27.9 °C in July, the hottest month. The mean temperature in Lisbon in the hottest month (August) is 23.5 °C.

In the maps shown in Figures 3 and 4, the numbers of heating degree days and cooling degree days are presented. Very clear differences between the region around Mediterranean Basin and the other European regions can be observed. In Table 1, some examples of heating and cooling degree days for European cities are given.

![Fig. 3 – European heating degree days (Eurostat method, Boermans and Petersdorff 2007).](image)
Fig. 4 – European cooling degree days (ASHRAE method, Boermans and Petersdorff 2007).

Table 1 – Number of Heating and Cooling Degree Days for different European Cities (adapted from Tsikaloudaki et al 2012).

<table>
<thead>
<tr>
<th>CITY</th>
<th>HDD</th>
<th>CDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aberdeen</td>
<td>3530</td>
<td>2</td>
</tr>
<tr>
<td>Athens</td>
<td>1112</td>
<td>1075</td>
</tr>
<tr>
<td>Belgrade</td>
<td>2798</td>
<td>423</td>
</tr>
<tr>
<td>Berlin</td>
<td>3155</td>
<td>170</td>
</tr>
<tr>
<td>Bilbao</td>
<td>1612</td>
<td>171</td>
</tr>
<tr>
<td>Brussels</td>
<td>2911</td>
<td>95</td>
</tr>
<tr>
<td>Larnaca</td>
<td>759</td>
<td>1260</td>
</tr>
<tr>
<td>Lisboa</td>
<td>1087</td>
<td>474</td>
</tr>
<tr>
<td>Madrid</td>
<td>1965</td>
<td>628</td>
</tr>
<tr>
<td>Malaga</td>
<td>796</td>
<td>791</td>
</tr>
<tr>
<td>Milan</td>
<td>2639</td>
<td>380</td>
</tr>
<tr>
<td>Rome</td>
<td>1443</td>
<td>648</td>
</tr>
<tr>
<td>Stockholm</td>
<td>4239</td>
<td>36</td>
</tr>
<tr>
<td>Tambere</td>
<td>5020</td>
<td>23</td>
</tr>
<tr>
<td>Warsaw</td>
<td>3614</td>
<td>103</td>
</tr>
</tbody>
</table>

In what concerns solar irradiation differences are also quite relevant as it can be observed in Figure 5.

Fig. 5 – Global Horizontal Irradiation in Europe (from http://solargis.info/doc/maps-for-solar-energy).
Energy consumption in residential buildings

Due either to the climate or the life style, there are large differences in energy consumption per dwelling among southern and northern European countries. Figures 6, 8 and 9 show some evidences of this.

According to an analysis based on ODYSSEE and MURE databases (Gynther et al 2015), the comparison between countries is more relevant if the heating consumption is adjusted to the same climate, highlighting differences related to building characteristics and to type of uses and life style. After adjustment to the EU average climate, Figure 6 shows that Luxembourg and Belgium turn out to have the highest consumption, at around 2 toe/dwelling (i.e. 23000 kWh), compared to 0.3 toe/dwelling (3500 kWh) in Malta or 0.8 toe/dwelling (9300 kWh) in Portugal and Bulgaria.

![Figure 6 - Household energy consumption per dwelling (Gynther et al 2015).](image)

Space heating is the most important end-use in the residential sector in the EU (67% in 2012, according to figure 7) but its share has been slightly declining.

However, in a great part of European southern countries as it could be expected its share is much less than EU average: in Malta, Cyprus and Portugal the share of space heating is below 30% and below 50% in Spain (figures 8 and 9).
**Fig. 7 – Breakdown of household energy consumption by end-use in the EU (Gynther et al 2015).**

**Fig. 8 – Breakdown of household energy consumption by end-use for each EU country in 2012 (Gynther et al 2015).**
Case study

Scope
In order to identify the questions raised by low energy renovation at neighborhood level in a European southern country, a preliminary study was carried out in the scope of a M.Sc. work (Aires 2015), where a residential complex in Porto, Portugal, was evaluated in terms of energy use and possible renovation measures were identified and tested. This will be presented as a case study allowing the discussion of the main issues.

Characterization of the neighborhood
The object of the study was a set of buildings that constitutes the second phase of a wider complex, a neighborhood, promoted by a housing cooperative.

The set of buildings under study (bordered by a red line in figure 10) is a residential complex built in 1991 and designed by architect Manuel Correia Fernandes. It consists of eight buildings (numbered from A1 to A6 and B1 and B2), with 16 apartments each, in a total of 128 apartments distributed by typology as shown in Table 2.
Table 2 – Number of dwellings and inhabitants of the studied residential complex.

<table>
<thead>
<tr>
<th>Typology</th>
<th>Number of dwellings</th>
<th>Number of inhabitants</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 bedrooms</td>
<td>42</td>
<td>126</td>
</tr>
<tr>
<td>3 bedrooms</td>
<td>14</td>
<td>56</td>
</tr>
<tr>
<td>4 bedrooms</td>
<td>36</td>
<td>180</td>
</tr>
<tr>
<td>5 bedrooms</td>
<td>36</td>
<td>216</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>128</strong></td>
<td><strong>578</strong></td>
</tr>
</tbody>
</table>

This residential complex is located in Porto, Portugal. The climate of Porto is classified as Csb Mediterranean. The mean temperature in the coldest month (January) is 9.5 °C and in the warmest month (August), 20.8 °C. The standard number of heating degree-days is 1250 °C.

Fig. 10 – Aerial view of the studied residential complex.

In figures 11, 12 and 13, some architectural drawings and photos of the residential complex are presented.

Fig. 11 - Ground-floor plan.

Fig. 12 - First floor plan.
The envelope of the buildings consists of external double walls (hollow brick + air space + solid brick, with no thermal insulation) and a flat roof (a concrete slab with 0.04 m of thermal insulation). The internal concrete slabs in contact with the garages have no thermal insulation. The windows have PVC frames, a single glass with a thickness of 5 mm and external roller shutters. In Table 3, the U-values of these construction elements are presented.
Table 3 – U-values of the buildings envelope.

<table>
<thead>
<tr>
<th>Element</th>
<th>U [W/(m²K)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>External walls</td>
<td>1.14</td>
</tr>
<tr>
<td>Flat roof</td>
<td>0.7</td>
</tr>
<tr>
<td>Internal slabs</td>
<td>2.56</td>
</tr>
<tr>
<td>Windows</td>
<td>3.80</td>
</tr>
</tbody>
</table>

Field Survey

A field survey was carried out gathering all possible information about the following:

- Type of occupation (permanent or temporary);
- Energy consumption habits;
- Type of equipment used to meet space heating (figure 14) and cooling needs (figure 15);
- Type of ventilation system (figure 16);
- Type of equipment to prepare domestic hot water (DHW) (figure 17).

![Fig. 14 – Equipment used for space heating.](image)
Fig. 15 – Equipment used for space cooling.

Fig. 16 – Ventilation system.

Fig. 17 – Equipment for DHW.
The field survey allowed gather some energy bills. However, since it was a preliminary study of short duration, given the small number of replies it would not be possible to draw reliable conclusions about the actual energy consumption but with the help of the energy matrix of Porto it was possible to define an average user profile.

The energy matrix of the metropolitan area of Porto (Oliveira Fernandes et al 2014) presents, for the residential sector, in terms of final energy consumption, the following estimation for each type of use: space heating (22%), DHW (22%), domestic cold, i.e. fridges and freezers (17%), cooking (17%), appliances (16%), lighting (6%) and space cooling (1%). These are average figures and of course it is possible to find specific examples of different behaviors, depending on the building and especially on its use. However, an analysis of all the information gathered for the studied residential complex made it possible to accept this distribution as an average user profile, suitable for the purpose of the present preliminary study although certainly not enough accurate for a real intervention.

**Estimation of energy needs**

Buildings energy needs were estimated using the methodology of Portuguese thermal regulation for residential buildings which is a steady-state methodology that follows European standards and assumes the conditions described below. It takes into account heating energy needs, cooling energy needs, energy for DHW and the contribution of possible local production of renewable energy.

For winter, the regulatory methodology considers a comfort indoor temperature of 18°C, 24/24 hours during all the heating season. The duration of this season is defined in the regulation, for each location, based on the period for which the number of GD is quantified. For Porto, the standard duration of the heating season is of 6.2 months. This means that the regulation assumes that residential buildings in Porto region are permanently heated at 18°C during 6.2 months in the year.

For cooling season, a duration of 4 months and an indoor comfort temperature of 25°C are considered by the regulation.

For the estimation of energy need for DHW, the hot water consumption is of 40 litres per person per day. The existing buildings characterized above have no installed solar collectors or any other renewable energy source.

Among the 128 dwellings of the residential complex, 16 groups were identified of apartments sharing the same relevant characteristics for the calculation. In Tables 4, 5 and 6, the results for the heating, cooling and DHW conventional energy needs of the buildings are presented.

**Table 4 – Heating and cooling conventional energy needs for buildings from A1 to A6.**

<table>
<thead>
<tr>
<th>Group of apartments</th>
<th>Apartment area (m²)</th>
<th>Heating conventional energy needs (kWh/ m²year)</th>
<th>Cooling conventional energy needs (kWh/ m²year)</th>
<th>Energy Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>60.40</td>
<td>49.63*/58.51</td>
<td>7.89*/7.02</td>
<td>C</td>
</tr>
<tr>
<td>Group 2</td>
<td>78.23</td>
<td>37.00*/46.77</td>
<td>8.00*/7.63</td>
<td>C</td>
</tr>
<tr>
<td>Group 3</td>
<td>109.51</td>
<td>49.34*/60.19</td>
<td>8.23*/6.49</td>
<td>C</td>
</tr>
<tr>
<td>Group 4</td>
<td>94.95</td>
<td>54.68*/64.47</td>
<td>8.02*/7.49</td>
<td>C</td>
</tr>
<tr>
<td>Group 5</td>
<td>119.25</td>
<td>36.46*/36.45</td>
<td>17.33*/17.33</td>
<td>B</td>
</tr>
<tr>
<td>Group 6</td>
<td>109.65</td>
<td>30.49*/30.53</td>
<td>17.07*/17.06</td>
<td>B</td>
</tr>
<tr>
<td>Group 7</td>
<td>123.04</td>
<td>50.68*/47.32</td>
<td>16.87*/14.92</td>
<td>B</td>
</tr>
<tr>
<td>Group 8</td>
<td>134.00</td>
<td>51.27*/47.54</td>
<td>15.99*/16.86</td>
<td>B</td>
</tr>
</tbody>
</table>
Table 5 – Heating and cooling conventional energy needs for buildings B1 and B2.

<table>
<thead>
<tr>
<th>Group of apartments</th>
<th>Apartment area (m²)</th>
<th>Heating conventional energy needs (kWh/ m².year)</th>
<th>Cooling conventional energy needs (kWh/ m².year)</th>
<th>Energy Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 9</td>
<td>72.07</td>
<td>23.09</td>
<td>10.35</td>
<td>B</td>
</tr>
<tr>
<td>Group 10</td>
<td>131.24</td>
<td>34.68</td>
<td>10.79</td>
<td>B</td>
</tr>
<tr>
<td>Group 11</td>
<td>92.37</td>
<td>25.85</td>
<td>11.15</td>
<td>B</td>
</tr>
<tr>
<td>Group 12</td>
<td>102.5</td>
<td>41.49</td>
<td>9.69</td>
<td>B</td>
</tr>
<tr>
<td>Group 13</td>
<td>103.11</td>
<td>56.91</td>
<td>14.25</td>
<td>C</td>
</tr>
<tr>
<td>Group 14</td>
<td>117.04</td>
<td>76.36</td>
<td>13.90</td>
<td>C</td>
</tr>
<tr>
<td>Group 15</td>
<td>104.34</td>
<td>63.32</td>
<td>13.62</td>
<td>C</td>
</tr>
<tr>
<td>Group 16</td>
<td>115.81</td>
<td>73.16</td>
<td>13.87</td>
<td>C</td>
</tr>
</tbody>
</table>

Table 6 – Conventional energy needs for DHW (kWh/year).

<table>
<thead>
<tr>
<th>Building</th>
<th>Conventional energy needs for DHW (kWh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>42,793</td>
</tr>
<tr>
<td>A2</td>
<td>42,793</td>
</tr>
<tr>
<td>A3</td>
<td>42,793</td>
</tr>
<tr>
<td>A4</td>
<td>42,793</td>
</tr>
<tr>
<td>A5</td>
<td>42,793</td>
</tr>
<tr>
<td>A6</td>
<td>42,793</td>
</tr>
<tr>
<td>B1</td>
<td>43,387</td>
</tr>
<tr>
<td>B2</td>
<td>43,387</td>
</tr>
</tbody>
</table>

Low energy renovation measures

The reduction of a building energy needs can be pursued through an adequate combination of four key points: urban integration (which defines the surrounding microclimate), design strategies (whose options influences the way the building interact with the climate), building technologies (sustainable and economical viable construction solutions must be chosen) and energy efficiency of all systems and equipment used in the building. Figure 18 represents this idea.

For existing buildings the options are of course more limited when compared to new buildings. There can be several restrictions either physical or economical. One of the aims of the present study was the test of some possible low energy renovation measures.

After analyzing the energy needs and consumption of the studied buildings some measures were defined in order to reduce the energy needs: a) To add thermal insulation to internal concrete slabs in contact with the garages to which important heat losses were calculated (new U-value of 0.67 W/m²K); b) To insulate the external walls (new U-value of 0.47 W/m²K); c) Replacement of all the incandescent light bulbs for LED lights; d) Replacement of all the electrical appliances presenting low energy efficiency for Class A appliances.
As seen before, the estimation of the energy needs was done for the conventional heating conditions assumed by the regulation methodology but as several field surveys have showed before and the one undertaken for the residential complex under analysis confirmed, this conventional scenario has little correspondence to the reality of heating energy consumption. In fact, the heating habits are far below this level. For the average user profile in the present case study, the percentage of 22% of total energy consumption for space heating pointed out by the energy matrix of Porto (Oliveira Fernandes et al 2014) seemed to be a very plausible figure, compared to the gathered energy bills and to the inquiry to the residents. It was also noticed that the value of 22% corresponds roughly to one third of the estimated conventional heating energy needs. In practical terms this can be looked at as describing a situation where the residents only heat their houses for 8 hours each day or in a third of the duration of the conventional heating season. Knowing the heating habits of Portuguese families this seems to be a fairly accurate portrayal of the situation.

In Table 7, a synthesis of the results for the insulation of the concrete slabs over the garages is given.

<table>
<thead>
<tr>
<th>Building</th>
<th>Unit cost (€/m²)</th>
<th>Area of application (m²)</th>
<th>Total cost (€)</th>
<th>Annual savings for standard conditions (€)</th>
<th>Annual savings for average user profile (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1, A3, A4, A6</td>
<td>41.58</td>
<td>193.12</td>
<td>8,030</td>
<td>1,470.16</td>
<td>479.27</td>
</tr>
<tr>
<td>A2, A5</td>
<td>41.58</td>
<td>193.12</td>
<td>8,030</td>
<td>1,378.02</td>
<td>449.23</td>
</tr>
<tr>
<td>B1, B2</td>
<td>41.58</td>
<td>193.12</td>
<td>8,030</td>
<td>1,724.14</td>
<td>562.07</td>
</tr>
<tr>
<td>Residential complex</td>
<td>41.58</td>
<td>1,544.96</td>
<td>64,240</td>
<td>12,084.96</td>
<td>3,939.38</td>
</tr>
</tbody>
</table>

A simple calculation of the payback period for the first renovation measure, from Table 7, gives us a value of 5.3 years for standard conditions and a value of 16.3 years for the adopted average user profile.

In Table 8, the results for the thermal insulation of external walls are presented.
Table 8 – Results for the thermal insulation of external walls.

<table>
<thead>
<tr>
<th>Building</th>
<th>Unit cost (£/m²)</th>
<th>Area of application (m²)</th>
<th>Total cost (£)</th>
<th>Annual savings for standard conditions (€)</th>
<th>Annual savings for average user profile (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1, A3, A4, A6</td>
<td>30.10</td>
<td>522.26</td>
<td>15,720.03</td>
<td>1,996.82</td>
<td>650.96</td>
</tr>
<tr>
<td>A2, A5</td>
<td>30.10</td>
<td>522.26</td>
<td>15,720.03</td>
<td>1,943.10</td>
<td>633.45</td>
</tr>
<tr>
<td>B1, B2</td>
<td>30.10</td>
<td>571.78</td>
<td>17,210.58</td>
<td>2,271.54</td>
<td>740.35</td>
</tr>
<tr>
<td>Residential complex</td>
<td>30.10</td>
<td>4,277.12</td>
<td>128,741.34</td>
<td>16,296.56</td>
<td>5,312.68</td>
</tr>
</tbody>
</table>

From Table 8, the payback period for the second renovation measure would be of 7.9 years for standard conditions and of 24.2 years for the estimated average user profile.

The use of LED light bulbs saves, when compared to incandescent bulbs, about 80% of energy. Table 9 presents a comparison between the typical 60W incandescent light bulb and 11W LED light bulb, with respect to cost, energy consumption and service life.

Table 9 – Comparison between incandescent and LED light bulbs.

<table>
<thead>
<tr>
<th></th>
<th>Incandescent (60W)</th>
<th>LED (11W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service life (hours)</td>
<td>1000</td>
<td>8000</td>
</tr>
<tr>
<td>Price of each light bulb (£)</td>
<td>1.20</td>
<td>7.00</td>
</tr>
<tr>
<td>Energy consumption (kWh) (8000 operating hours)</td>
<td>480</td>
<td>88</td>
</tr>
<tr>
<td>Total cost of light bulbs (£) (for 8000 operating hours)</td>
<td>9.60</td>
<td>7.00</td>
</tr>
<tr>
<td>Energy cost (£)</td>
<td>67.20</td>
<td>12.32</td>
</tr>
<tr>
<td>Total cost (£)</td>
<td>76.80</td>
<td>19.32</td>
</tr>
</tbody>
</table>

An estimation was done for replacement of 20 light bulbs in each dwelling, choosing LED bulbs with a price of 4.99 euros, meaning an investment of 99.8 euros per dwelling.

Considering the actual energy consumption of an average dwelling of the neighborhood under analysis, based on the energy bills gathered, the annual energy consumption for lighting was estimated of about 580 kWh. If this consumption is related mainly to the use of incandescent light bulbs, their simple replacement would reduce energy consumption for lighting to 116 kWh per year. Table 10 presents the analysis in terms of costs and savings of the application of this measure.

Table 10 – Costs and savings concerning the replacement of light bulbs.

<table>
<thead>
<tr>
<th></th>
<th>Unit cost (£)</th>
<th>Number of replaced light bulbs</th>
<th>Total cost (£)</th>
<th>Estimated annual savings (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apartment</td>
<td>4.99</td>
<td>20</td>
<td>99.8</td>
<td>78.88</td>
</tr>
<tr>
<td>Building</td>
<td>4.99</td>
<td>320</td>
<td>1,596.8</td>
<td>1,262.00</td>
</tr>
<tr>
<td>Residential complex</td>
<td>4.99</td>
<td>2560</td>
<td>12,774.4</td>
<td>10,097.00</td>
</tr>
</tbody>
</table>
Table 10 shows that the savings would pay the investment in LED light bulbs in just a little more than a year.

In order to study the impact of the replacement of all the less efficient electrical equipment for more efficient ones, based on the analysis of current energy consumption, a value of 3500 kWh per year was considered for electricity consumption of that equipment in each apartment. For a reduction of 30% of that consumption, the acquisition of the following Class A equipment for each apartment was evaluated: a washing machine, a dishwasher, a fridge, a freezer and a stove with oven. The investment would be around 1500 € per dwelling. Table 11 presents the significant numbers for this measure.

**Table 11 – Replacement of less efficient equipment for Class A equipment.**

<table>
<thead>
<tr>
<th></th>
<th>Cost (€)</th>
<th>Energy consumption reduction (kWh/year)</th>
<th>Estimated annual savings (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apartment</td>
<td>1,500</td>
<td>1,050</td>
<td>178.5</td>
</tr>
<tr>
<td>Building</td>
<td>24,000</td>
<td>16,800</td>
<td>2,856.0</td>
</tr>
<tr>
<td>Residential complex</td>
<td>192,000</td>
<td>134,400</td>
<td>22,848.0</td>
</tr>
</tbody>
</table>

The payback period for this measure would be at least 8.4 years.

In what concerns the equipment for space heating and cooling, no replacements were considered. In the case of cooling, as figure 15 shows, the great majority of the apartments have no equipment. The few ones that have fans or air-conditioners use them for very short periods in a year so it is not significant.

In the case of heating, since very diverse solutions were found in the studied buildings and the way they are used also vary a lot, it would take a deeper analysis to be able to define a realistic approach which would fall out of the scope of the preliminary study undertaken.

**Renewable energy**

Concerning local renewable energy production, the installation of thermal and PV solar systems was evaluated. To meet the energy needs for DHW, presented in Table 6, solar thermal collectors were designed to be installed on the roof with an area of 1.9 m² each and an optical efficiency of 82%. Very well-insulated water tanks are necessarily components of the global system. Table 12 summarizes the performed calculation.

**Table 12 – Solar collectors for heating DHW.**

<table>
<thead>
<tr>
<th>Building</th>
<th>Energy needs for DHW (kWh/year)</th>
<th>Number of solar collectors</th>
<th>Total area of collectors (m²)</th>
<th>Cost (€)</th>
<th>Energy provided by the collectors (kWh/year)</th>
<th>Energy required from the support electrical system (kWh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 to A6</td>
<td>42,793</td>
<td>37</td>
<td>70.3</td>
<td>49,810</td>
<td>40,646</td>
<td>2,147</td>
</tr>
<tr>
<td>B1, B2</td>
<td>43,387</td>
<td>37</td>
<td>70.3</td>
<td>49,810</td>
<td>40,646</td>
<td>2,741</td>
</tr>
<tr>
<td>Residential complex</td>
<td>343,532</td>
<td>296</td>
<td>562.4</td>
<td>398,480</td>
<td>325,168</td>
<td>18,364</td>
</tr>
</tbody>
</table>
The annual savings were estimated as 55,000 euros for the residential complex which means that the payback period would be around 7.2 years.

After applying the measures to reduce energy needs and sizing solar thermal collectors for the preparation of DHW, if net zero energy standard is to be meet it is possible to try to cover the remaining energy needs with PV solar panels.

To produce the energy necessary to meet the needs of the buildings, photovoltaic panels were designed as follows: groups of PV panels which comprises two modules with an area of 1.14 m$^2$, with an open circuit voltage of 24.5 V, intensity of current of 8.1 A for short circuit and a nominal power of 150 W, connected to an inverter with an output of 3300 W and an efficiency of 95% at full load and an output of 330 W and an efficiency of 88% at 10% of the load. Table 13 presents the main information related with the foreseen installation of a PV solar system.

### Table 13 – PV solar panels.

<table>
<thead>
<tr>
<th>Building</th>
<th>Energy needs (kWh/year)</th>
<th>Number of groups of panels</th>
<th>Total area of panels (m$^2$)</th>
<th>Total energy provided by the PV system (kWh/year)</th>
<th>Unit cost (€)</th>
<th>Total cost (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1, A3, A4, A6</td>
<td>43,685</td>
<td>123</td>
<td>280.9</td>
<td>43,847</td>
<td>461.5</td>
<td>56,764.5</td>
</tr>
<tr>
<td>A2, A5</td>
<td>41,649</td>
<td>115</td>
<td>262.7</td>
<td>40,996</td>
<td>461.5</td>
<td>53,072.5</td>
</tr>
<tr>
<td>B1, B2</td>
<td>45,146</td>
<td>128</td>
<td>292.4</td>
<td>45,630</td>
<td>461.5</td>
<td>59,072.0</td>
</tr>
<tr>
<td>For DHW (all buildings)</td>
<td>18,364</td>
<td>50</td>
<td>114.2</td>
<td>18,405</td>
<td>461.5</td>
<td>23,375.0</td>
</tr>
<tr>
<td>Residential complex</td>
<td>366,694</td>
<td>1,028</td>
<td>2,357.0</td>
<td>367,045</td>
<td>461.5</td>
<td>474,722.0</td>
</tr>
</tbody>
</table>

The annual savings with the installation of the PV system, in the theoretical hypothesis of an integral use of the produced energy, would be of 63,398 euros which means that PV system would have a payback period around 7.5 years. However, this figure can be deceiving since it would only be possible if either some storage capacity was implemented or an efficient energy exchange with the grid was in place, preferably through a smart grid. Furthermore, the preliminary calculation presented in this paper pointed to an area of thermal and PV solar systems bigger than the available area in the buildings roofs. Adaptations of the façades or the use of public common spaces would be necessary. This would imply an even more significant investment.

### Smart energy management

As mentioned above, for the presented case study, storage capacity and its costs were not evaluated nor the sale of electricity to the grid nor the costs of the implementation of a smart energy management system. This means that no reliable calculation of the global payback period is possible. However further research will address these important topics.

In terms of energy management a neighborhood is a geographically localized community within a larger city, town or suburb sharing a common service infrastructure, a group of households and public services served by a same electricity local Distribution System Operator (local DSO). In this context it is important to bring together the different prosumers (consumers that also produce energy) and the DSO in order to maximize energy efficiency.
In the context of the EU FP-7 NOBEL project (Neighborhood Oriented Brokerage Electricity and monitoring system, 2010-2012, http://www.ict-nobel.eu/) the relevant components for a neighborhood-oriented system were identified, from intelligent appliances to a smart distribution at a local level. Furthermore implementing a smart grid must include the following typical components (Karnouskos et al 2011):

- Intelligent appliances capable of deciding when to consume power based on pre-set customer preferences;
- Smart power meters empowering bidirectional communication between consumers and power providers for better data collection, maintenance, outage detection etc.;
- Smart substations that include monitoring and control of critical and non-critical operational data;
- Smart distribution that depicts self-features such as self-healing, self-balancing and self-optimization;
- Smart generation capable of “learning” the unique behavior of power generation resources to optimize energy production;
- Universal access to affordable, low-carbon electrical power generation (e.g., wind turbines, concentrating solar power systems, photovoltaic panels) and storage (e.g., in batteries, flywheels or super-capacitors).

Discussion

Table 14 presents a synthesis of the results presented in previous paragraphs.

**Table 14 – Synthesis of results.**

<table>
<thead>
<tr>
<th>Renovation measure</th>
<th>Total cost (€)</th>
<th>Reduction in energy consumption (kWh/year)</th>
<th>Annual savings (€)</th>
<th>Payback period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation of the slabs over the garages</td>
<td>64,240</td>
<td>23,173 (1)</td>
<td>3,939</td>
<td>16.3</td>
</tr>
<tr>
<td>Insulation of external walls</td>
<td>128,741</td>
<td>31,251 (1)</td>
<td>5,313</td>
<td>24.2</td>
</tr>
<tr>
<td>Replacement of light bulbs</td>
<td>12,774</td>
<td>59,392</td>
<td>10,097</td>
<td>1.3</td>
</tr>
<tr>
<td>Replacement of energy non-efficient equipment</td>
<td>192,000</td>
<td>134,400</td>
<td>22,848</td>
<td>8.4</td>
</tr>
<tr>
<td>Installation of solar thermal collectors</td>
<td>398,480 (2)</td>
<td>325,168 (3)</td>
<td>55,000</td>
<td>7.2</td>
</tr>
<tr>
<td>Installation of PV solar panels</td>
<td>474,722 (2)</td>
<td>367,045 (3)</td>
<td>63,398</td>
<td>7.5</td>
</tr>
<tr>
<td>Total</td>
<td>1,270,957</td>
<td>940,429</td>
<td>160,595</td>
<td>7.9</td>
</tr>
</tbody>
</table>

From Tables 7, 8 and 14, it can be observed that in the actual conditions of use of the buildings, the increase of thermal insulation has just a slight influence on annual savings. Payback periods ranging from 15 to 25 years are in fact too long.

Portuguese regulation, following the European Directive, demands the compliance with certain requirements in buildings subjected to renovation. The requirement to be applied to walls, floors and
roofs is a maximum allowable U-value. Those values have been gradually reduced in accordance to European trend. From January 2016 on, the maximum U-value for external walls ranges from 0.35 to 0.50 W/m²K, depending on the climatic zone and the maximum U-value for floors and roofs ranges from 0.30 to 0.40 W/m²K.

As seen in this case study, the actual savings obtained with the increase of thermal insulation are usually not very significant due to the climate and to low space heating habits. This means that this extra investment may expect a quite long payback period. In fact, a slight energy consumption reduction is not an argument convincing enough for the owners. Furthermore, if an extra insulation can bring some advantages in terms of thermal comfort in winter, this is not assured in summer for Mediterranean climate. A computer simulation study carried out on the influence of increasing thermal insulation on summer thermal comfort (Chvatal and Corvacho 2009) showed there is a turning point where, depending on thermal inertia, ventilation and heat gains, an increase in thermal insulation leads to an increase of the number of hours of discomfort in summer. In the left side of figure 19, an example of the variation of the percentage of hours of discomfort in summer, for a location in Portugal, in function of the level of insulation of the envelope is given for different values of the shading factor. If solar gains are high (non-existing or non-efficient shading) it can be observed that a high level of insulation may be harmful. An efficient night ventilation can reduce that effect as shown in the right side of figure 19.

![Fig. 19 – The influence of increasing thermal insulation upon thermal comfort in a residential building (indoor temperature maximum for summer comfort: 25 °C) in summer in Portugal (adapted from Chvatal and Corvacho 2009).](image)

This said, the regulatory requirements now in force instead of being an incentive to renovation are often an obstacle and a cause of demotivation for the building owners.

In what concerns the use of LED light bulbs, as proved, the savings can be really significant and the additional investment is easily recovered.

The replacement of less efficient electrical appliances for Class A equipment, as shown in Table 11, may represent annual savings of almost 23,000 euros for the entire residential complex. However for the individual owner the investment is considerable and a payback of more than 8 years is not very appealing.
The installation of solar thermal collectors has proven very effective and the availability of high solar irradiation makes a high solar fraction for DHW possible. However the calculation performed implies the existence of well-insulated water tanks and a collective system.

PV solar panels are an interesting possibility but as mentioned before in order to be really advantageous some storage capacity would have to be implemented or an efficient energy exchange with the grid, within a smart management of energy use.

**Conclusions**

In countries where space heating energy consumption represents just a small percentage of total energy consumption in buildings, the argument in favor of a higher level of thermal insulation should be an increase in comfort and not an energy consumption reduction or financial savings. In fact those reduction and savings are not very significant and lead to long payback periods. Besides, in what concerns summer comfort, a particular care must be taken. Beyond a certain level of insulation the intervention is useless or even harmful. Regulatory requirements should take these facts into account in order not to be an obstacle to renovation but an incentive.

In what concerns energy efficiency of domestic appliances and equipment, the replacement of less efficient ones may represent a considerable investment for a household so it is important that this replacement lead to significant and demonstrable savings.

The knowledge of the actual energy consumption has proved to be crucial, especially in countries with a favorable climate like in European southern countries. In these conditions life style determines in a great measure the energy consumption and so this can vary a lot due to social and economic factors. In order to be efficient stakeholders should be aware of this facts.

The residential complex used as a case study can be considered as representative of a great part of Portuguese building stock especially the one built before any thermal regulation came into force, which means before 1991. This part of the building stock needs refurbishment and moving the focus of those works from adding excessive thermal insulation to a reasonable integrated approach, moving from looking at each building individually to looking at a set of buildings would allow a higher flexibility of solutions. As seen in the case study, the implementation of renewable energy local production, in the present case solar systems, can only meet the full use of its potential in an integrated approach, comprising a number of buildings and shared infrastructures, places and a common energy management system. Moving from a building to a neighborhood scale may be an interesting challenge for policy makers to look closer in the near future.

**Acknowledgments**

The authors are thankful to Marco Aires the author of the Master Thesis used as a case study in this paper.

**References**


Session 4: Building energy demand and supply, and low carbon technologies
Synergistic benefits of renewable energy sources and electric vehicles in autonomous grids

Evanthia A. Nanaki 1, George A. Xydis 2, Christopher J. Koroneos 3

1) Centre for Research and Technology Hellas, Institute for Research & Technology of Thessaly, Technology Park of Thessaly, 1st Industrial Area, 38500 Volos, Greece. Email: evananaki@gmail.com
2) Soft Energy Applications & Environmental Protection Lab, Piraeus University of Applied Sciences, P.O. Box, 41046, Athens 12201, Greece. Email: gxydis@gmail.com
3) Dept. of Mechanical Engineering University of Western Macedonia, Greece. Email: koroneos@aix.meng.auth.gr

Abstract: The availability of power, based on intermittent renewable energy sources, depends on various factors such as the weather and the time during the day. Given the significant amounts of renewable energy integration in modern systems, the systems designers are facing the challenge of meeting the electricity demand day and night. This is more intense in autonomous grids and the most common way to confront this is via hybrid systems. A hybrid renewable energy system consists of two or more renewable energy sources; typical of islands is a system of a wind farm – PVs – batteries.

The electricity demand on a Greek island over a period of a year was recorded and a hybrid system was designed based on the different demand profiles (summer, winter, spring / autumn, holidays, working days, etc). The optimal dimensioning of a stand-alone grid renewable energy driven electricity generation system was implemented based on the contribution of the Electric Vehicles (EVs) via the technology vehicle to grid (V2G) & Grid to Vehicle (G2V). The basic concept is to replace the required battery capacity for the hybrid system operation with Electric Vehicles (EVs). Therefore, a significant cost of the hybrid system shall be covered by the car owners and energy management shall be done by via the charging stations and the local grid operator. Last, critical parameters were altered to see how the grid’s load was affected and if higher amounts of renewable energy sources penetration were achieved.

Keywords: hybrid system; electric vehicles; autonomous grids; island communities

Introduction

Supplying energy to islands through grid-based or autonomous systems is of great significance for the social and economic vitality of an island. At present, the current electricity mix of most small islands is dominated by fossil fuels, mainly diesel or heavy fuel oil. This is attributed to the relative ease with which fuel can be purchased and supplied, the flexibility of the installed engines in meeting daily and seasonal variations in energy demand as well as to its reliability, ease of transportation, installation and disconnection. In addition, diesel engines’ efficient operation, along with their relatively low installation and maintenance costs, has made this technology a preferable solution for many islands.

Electrical energy shortage is one of the most severe problems on non-interconnected islands of the Mediterranean Sea, as well as on Aegean islands. Greece has over 6,000 islands, islets and rocks. Of all these islands only 127 are inhabited and only 79 of them have a population of more than 100 residents. Out of these 36 are non-interconnected islands (NII) with a peak load demand ranging from 100 kW to 700 MW. The primary power supply is based on various types of heavy and light fuel oil.
Greek islands are characterized by inequalities, demographic decline, high conventional energy cost but have a high RES potential and diversity of resources.

Given that Greece is facing major challenges, since it has to implement the National Renewable Energy Action Plan, in the context of the European Energy Policy (regarding RES integration, energy saving and greenhouse gas emissions reduction) the implementation of new RES technologies on islands is a promising solution for a sustainable energy system. Climate protection, through the promotion of electrical energy production from RES, constitutes an environmental and energy priority of the highest significance for the country (Law 3851/2010). It sets specific targets for RES electricity share (40%), RES heating and cooling share (20%), and RES transport share (10%), with objective to achieve the national target of 20% contribution of RES to the total energy use by the year 2020. Based on the abovementioned, it is evident that the role of RES is very important for country where the RES sources are abundant. Although there are some wind farms and small-scale solar systems, large-scale hybrid systems are limited.

Various studies have been carried out regarding the system design for optimal dimensioning of a stand-alone grid renewable energy driven electricity generation system, including inter alia the studies of Dalton et al. (2008), Bajpai and Dash (2012), Praene et al. (2012) as well as Kumar et al. (2013). The operation of energy storage systems in hybrid power systems has also been discussed in many studies (Serban, 2014; Jayasinghe et al, 2011; Sebastian 2013; Goel et al, 2011). Emphasis has also been given to the economic analysis of these systems (Zoulas and Lymberopoulos, 2007; Diaf et al., 2008; Liu and Wu, 2010). Nevertheless, the deployment of RES is limited to standalone areas, such as islands, due to the seasonality of energy demand. In this direction, some studies throw light on the deployment of RES (Silva et al. 2013).

This study aims to investigate the opportunities for integrated electricity deployment on the basis of the wind and solar potential of the Greek islands, so as to highlight the benefits of increased RES technology penetration as well as the relative cost reductions. In this regard, the main objectives of this study are to: i) highlight the importance of the RES, ii) examine the potential of Vehicle to Grid (V2G) technology in combination with renewable energy sources when they are utilized in a smart grid, iii) investigate a hybrid renewable energy system from the economical point of view, iv) calculate the performance parameters, and examine the effects of some operating and system parameters.

**Methods – System description**

In this study, a case study is undertaken for the island of Amorgos in Greece by considering supplying its electric energy demand from renewable energy sources. Amorgos is the easternmost island of the Prefecture of Cyclades and has a total area of 121 km² (the 7th largest island in the Cyclades) and 112 km of coastline (Fig. 1). The shape of the island is very elongated, with a length of about 32 km and oriented NE-SW. The resident population of Amorgos, according to 2011 census is 1,973; while the number changes according to tourism seasons (Hellenic Statistical Authority, 2015). Despite the fact that the entire region appreciates considerable wind and solar potential, current use of renewable energy on the island is limited. As a matter of fact, the local wind potential quality is determined by a mean annual wind speed in the order of 10 m/sec, which encourages investigation of wind-based energy solutions. However, the energy potential (RES), which at the moment consists of a few PVs, to be exploited in the island is quite high.
To supply the primary energy, we take into consideration the installed thermoelectric diesel units with total power output of 5,286 MW. Fig. 2 illustrates the proposed configuration, which comprises of a wind park coupled with battery storage, supported also by the minimum contribution of the local autonomous power station of Amorgos. At the same time, the proposed configuration also employs photovoltaic panels. The wind turbines produce alternative current (AC) and supply direct power to the load without having to be diverted; nonetheless as the PV modules exit the direct current (DC), a converter is necessary to convert the DC to the AC or vice versa. A fleet of electric vehicles, operated by an aggregator is also being employed. It is noted that the hybrid system is not extended to replace the diesel generator totally, but to minimize the usage of diesel fuel and to use available renewable sources. In an autonomous grid system, the fluctuation in the voltage and frequency is due more to the dynamic changes in load and changes in load sharing by the renewable energy sources.

As the study focuses on the electricity need of the island of Amorgos using its renewable energy sources, it is necessary to define the optimal renewable hybrid system design. For this reason the Hybrid Optimization Model for Electric Renewable – HOMER is used. The program has been developed by the National Energy Renewable Laboratory (NREL), in order to simulate, optimize and provide sensitivity analysis for on- and off-grid renewable energy systems (Lambert, 2006). For a particular application scenario, inputs to HOMER include load data, renewable resource data, system component specifications, costs and various information of optimization (e.g. number of components).
The primary load demand of Amorgos during summer months is peaking daily between 08:00-10:00 and 20:00-22:00 at 3 MW. In the winter time the demand fluctuates between 0.7 MW and 1.2 MW. Four petrol engines are employed to light up the island, consuming approximately 13 cubic meters of diesel daily. Electricity network is split in three. One line is powering the northern small port town of Aegiali and the nearby villages, the second one supplies the mountainous Chora and the southern part of the island, while the third line supplies the small port town of Katapola where the production unit is located. Fig. 3, indicates that during the summer period and especially during July and August the electricity demand in Amorgos Island is higher, almost double, than the rest of the year. This is due to the population increase, since July and August are the main touristic months for Amorgos Island as well as for the whole Aegean Sea. It is also during the same period that electricity needs significantly increases; owed to the increased cooling needs and the use of air conditioning units.

The day-to-day and time-step-to-time-step variables are taken as 11.7% and 5.7%, respectively in the study. Using the data, the HOMER gives the load factor and peak load as 0.38 and 2.900 kW. Also the primary load is determined as 26.648 kWh/d. The operating reserves are taken as 25% and 50% of solar and wind power outputs, respectively.

To supply the energy, the simulation model takes into account two thermo-electric generators of 5.286 MW capacity. The first electricity generator, 500Kw Genset, simulates diesel units up to 500 kW; whereas the second generator, 2,000 kW Genset, simulates diesel units up to 2,500 kW. As per Law 3175/2003, which was aiming at the enhancement of market opening and competition in the electricity sector a Mandatory Pool System was introduced for power generation and wholesale supply, covering the entire market for the interconnected system. All suppliers got the obligations to purchase energy from the Pool and all generators can operate only if selected by the market operator according to their economic bids to the Pool. In order to allow for recovery of fixed and capital cost and therefore promote the construction of new power plants, generators acquired the right to submit free economic bids to the Pool, which have been restricted to reflect at least their variable costs. Based on the above, the initial capital, replacement and operational & maintenance costs (O & M) for 500 kW Genset are taken as 0, 200,000 and € 196,000, respectively with a 15,000 hours life time; whereas the initial capital, replacement and O & M costs for 2,500 kW Genset are 0, 1,200,000 and 196,000 respectively with a 15,000 hours life time (Table 1). These costs are entered into the HOMER tool.
Table 1 - Costs and lifetimes assumptions for the system components.

<table>
<thead>
<tr>
<th>Components</th>
<th>Initial Capital Cost (€/kW)</th>
<th>Replacement Cost (€/kW)</th>
<th>O&amp;M Cost in the first year (€/kW)</th>
<th>Lifetime (hrs &amp; years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen 500</td>
<td>0</td>
<td>200,000</td>
<td>4,000</td>
<td>15,000 hrs</td>
</tr>
<tr>
<td>Gen 2000</td>
<td>0</td>
<td>1,200,000</td>
<td>24,000</td>
<td>15,000 hrs</td>
</tr>
<tr>
<td>PV</td>
<td>1,100</td>
<td>1,100</td>
<td>22</td>
<td>20 years</td>
</tr>
<tr>
<td>G1500</td>
<td>2,700,000</td>
<td>2,700,000</td>
<td>54,000</td>
<td>20 years</td>
</tr>
<tr>
<td>V2G</td>
<td>6,000</td>
<td>5,000</td>
<td>300</td>
<td>8 years</td>
</tr>
</tbody>
</table>

The renewable potential of the island is defined according to its geographical and meteorological data. The geographical data for the island of Amorgos are 36,50N Latitude, 25,54E Longitude. The meteorological data for the year of 2014 were taken from the Greek National Meteorological Service [2015] and entered into the HOMER tool as the monthly average solar radiation, the monthly average wind speed, calculating from the hourly and daily data, as shown in Fig. 4a-4b. The wind speeds are high especially in winter; whereas the annual average wind speed is 6.28 m/s, as shown in Fig. 4a. The region has a good solar potential ranging from 1.98 to 7.89 kWh/m²d. The lowest solar radiation is 1.98 kWh/m²d in December, as given in Fig. 4b. According to this, the annual average solar radiation is 4.89 kWh/m²d.

Fig. 4.a and 4.b - Monthly average values: (a) wind speed and (b) daily solar radiation.

After the meteorological investigation, one of the most difficult problems associated with the design of the system is the optimization of different energy component sizes, with regards to the cost of energy and the overall system performance. The HOMER tool tries to optimize the equipment sizes in the system, taking into account the technical specification of the equipment, the system operation conditions and the minimization of the total NPC of the system. In the optimization process, while the photovoltaic (PV) array initial and capital replacement costs are taken €1,100/kW, the O&M costs and the life time are €22/kW and 20 years, respectively. The HOMER tool does not require any information on the PV array type or area, but considers the PV array sizing in terms of the required output rate in kW. The output rate is affected from the incident radiation. In the simulation, the PV size changes from 0 to 3,500 kW.
Wind turbine technology is a more mature than PV technology. Today wind turbine manufacturers produce from small scale turbines, watt, to large scale turbine, megawatt. The HOMER tool requires information on the turbine type to use its power curve and hub height data. Although the HOMER tool presents some turbine types in its library, a new turbine type can be created if it is necessary taking actual data from the manufacturer. In the simulation, a generic wind turbine of 1,500 kW is taken into consideration. The life time and hub height are taken 20 years and 80 m. The initial capital, replacement and O & M costs are taken 2,700 and €54/kW, respectively. The costs are entered into the HOMER tool for the selected turbine size.

Under the smart grid paradigm, coordinated charging and fleet participation should be implemented by an EV aggregator who acts as a load-serving entity (LSE), bidding in the day-ahead energy and in ancillary services markets on behalf of the EV owners, trying to minimize their charging costs. In this study an aggregator of 33.6 kWh V2G, managing a fleet of EVs equipped with NiMH batteries and with max. discharge rate of 80% is considered. The main costs that an aggregator must incur in order to be able to participate in the regulation market are the installation costs of a reliable and fast communication infrastructure with bidirectional data transfer between the aggregator and system operator (SO) and between aggregator’s data center and the EV charging stations. The cost of battery is still high, due to the lack of mass production. While the initial capital and replacement costs are taken as € 6,000/kW and € 5,000/kW respectively, the O&M cost is 300 and the life time is 8 years. Finally, a DC-AC power converter unit is added to the system for investigating an interval of 2,000 kW. While its initial capital and replacement cost considered is €10,000/kW, the O&M costs and the life time are zero and 15 years, respectively. Table 1 summarizes the above mentioned costs, while Fig. 5 depicts the energy system under study.

Techno-economical & environmental analysis

In the simulation, three scenarios, namely only PV array/aggregator V2G (Scenario 1), wind turbine/aggregator V2G (Scenario 2), PV array/aggregator V2G and wind turbine/ PV array/aggregator V2G (Scenario 3) for energy source, are considered. The current situation, with the production of electricity by thermoelectric diesel units, is described as Reference scenario. The NPC of the Reference scenario system is €65,500,580 while the COE is calculated as €0.523/kWh. At PV array/aggregator V2G (Scenario 1), the NPC and the COE of the system are given as €44,106,368 and €0.355/kWh. At wind turbine/aggregator V2G scenario (Scenario 2) the NPC of the system is € 35,640,656 while the COE is calculated as $0.287/kWh. At the wind turbine/ PV array/aggregator V2G (Scenario 3), the NPC and the COE of the system are given as €25,313,718 and €0.204/kWh. Fig. 6a-6b highlight the above.
Based on the aforementioned, it is noted that the optimum energy supply scenario is Scenario 3, with a payback period of 3.18 years. Compared with the current energy production situation as described in Reference Scenario the Net Present Cost is reduced by €40,186,862. Fig. 7, illustrates the differences between the cash flows in Reference Scenario and Scenario 3.
The optimum equipment size details described in Scenario are summarized in Table 2.

### Table 2 - Optimization results of the wind turbine/ PV array/aggregator V2G - Scenario 3.

<table>
<thead>
<tr>
<th>PV (kW)</th>
<th>G1500 (kW)</th>
<th>Gen 2000 (kW)</th>
<th>Gen 500 (kW)</th>
<th>Converter (kW)</th>
<th>Total NPC (€)</th>
<th>COE (€/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.500</td>
<td>3000</td>
<td>2500</td>
<td>500</td>
<td>2000</td>
<td>25,313,718</td>
<td>0.204</td>
</tr>
</tbody>
</table>

Energy storage is an important technological issue for renewable systems or islands, especially. They have to consider storage technologies, using normally batteries for low demands that are not economically viable on a large scale. Despite this, batteries continue to have a major role on this type of systems, especially on the real applied cases, as batteries are able to provide energy in case of resource unavailability, but also contribute to supply the quality control.

**Figure 8 - Emitted emissions per each scenario system under study.**

Finally, as illustrated in Fig. 8 the benefits of the optimum energy system for the island of Amorgos are not only economical, but also environmental as the hybrid energy system described in Scenario 3 reduces significantly the emitted air emissions. To be more specific CO₂ emissions in Reference Scenario reach 7,060,197 kg/year, whereas in Scenario 3 come up to 791,431 kg/year. CO emissions fall from 17,427 kg/year in Reference Scenario to 1,954 kg/year. HC and PM emissions also are reduced from 1,930 kg/year to 216 kg/year and from 1,314 kg/year to 147 kg/year respectively. As far as SO₂ emissions are concerned these fall from 14,178 kg/year to 1,589 kg/year. Finally NOₓ emissions are reduced from 155,503 kg/year to 17,432 kg/year.

### Conclusions

RES in autonomous systems can provide a solid instrument for meeting most objectives of the European energy policy: economic efficiency, environmental friendliness and security and diversification of supply. In this context, the developed methodology was accordingly applied to a representative, medium-scale island of the Aegean Sea, i.e. the island of Amorgos. According to the results obtained, the proposed solution achieves increased levels of energy autonomy. To be more specific, the simulation performed, using HOMER for the island of Amorgos, leads to the following concluding remarks:

- Meteorological data are very important to define the actual renewable energy potential of a region. So, the data should be taken from the local meteorological service or measured over a long period.
• The system optimization means that the system is designed with the most convenient equipment sizes to supply the primary load with the lowest NPC and COE values. In the simulation, the optimum system is determined as PV-3500 kW, wind turbine 1500 MW, 33.6 kWh V2G battery, converter-2000 kW, thermos-electric units of -500kW and 1500Kw.

• Using the wind turbine/PV array / V2G battery system (Scenario 3) instead of only thermos-electric diesel units (Reference Scenario describing current situation) decreases the NPC from €65,500,580 to €25,313,718; whereas the COE decreases from €0.523/kWh to €0.204/kWh.

• Using Scenario 3 instead of only Reference Scenario decreases significantly the CO₂ emissions (from 7,060,197 to 791,431 kg/year); CO emissions (17,427 to 1,954 kg/year); HC (1,930 to 216 kg/year); PM emissions (1,314 to 147 kg/year); SO₂ emissions (from 14,178 to 1,589 kg/year); NOx emissions (from 155,503 to 17,432 kg/year)

The process of “smartening” the electricity grid, which has already begun in many regions, involves significant additional upfront investment, though this is expected to reduce the overall cost of electricity supply to end users over the long term. Smart-grid technologies including V2G are evolving rapidly and will be deployed at different rates around the world, depending on local commercial attractiveness, compatibility with existing technologies, regulatory developments and investment frameworks.

This study provides policy makers with useful general guidelines and suggests some practical implications for an energy autonomous system. In addition, the analysis can help identify main factors, such as the crucial factor of energy supply, in order to develop projects which could contribute towards increasing the smartness of a region. Based on the results of this study, Greek islands have the potential of applying the abovementioned with significant economic and environmental benefits. Further study will focus on energy and exergy analyses of the present system.

References


Exploring the impact of product substitution in the supply of domestic thermal insulation in Wales

Fabrizio Varriale

Welsh School of Architecture, Cardiff University, Wales, UK. Email: varrialef@cardiff.ac.uk

Abstract: The built environment is responsible for significant pressure on the natural environment, in terms of greenhouse gas emissions as well as other categories of pollution. In order to decrease the impact from the production of building products, several researchers and environmental activists advocate the use of biomass-based primary materials, sourced and manufactured within the region. This paper quantifies the environmental benefits that could be gained by a regional uptake of biomass-based products for domestic thermal insulation, progressively substituting the synthetic and mineral products which are currently used.

Thermal insulation products are essential for energy efficiency in buildings, and their demand can be expected to increase in the future. The UK market for thermal insulation is currently dominated by synthetic and mineral products, whilst biomass-based ones remain a niche choice. In Wales, insulation products based on hemp fibre and sheep wool can be identified as potential candidates for meeting the regional demand for construction products with locally sourced and manufactured.

On the basis of a forecast of the future demand for thermal insulation in domestic buildings in Wales, supply scenarios are built to model a business-as-usual baseline and the progressive substitution of conventional products with biomass-based ones. The impact of each scenario is categorised and assessed through life-cycle analysis, and compared against the baseline in order to identify the environmental benefits and trade-offs implied by product substitution at the regional scale. Finally, in order to investigate the feasibility of a regional uptake of alternative insulation products, the demand for biomass generated by the substitution scenarios is compared to indicators of the potential supply in Wales.

The results of the research suggest that progressive substitution with biomass-based products can produce moderate reductions of environmental impact in the most important categories of pollution, although increases can take place in less important categories.

Introduction

The built environment and its related sector are responsible for a significant share of resource consumption and environmental pollution (UNEP 2008). This is due partly to the energy that is consumed by building services during operation and partly to the activities necessary to construct and demolish buildings, including the manufacture of building products. The environmental impact caused by the latter activities is called ‘embodied’ and it is generally considered smaller than the impact caused by the use of operational energy (NHBC Foundation 2014). However, it is acknowledged that as efforts are made to reduce operational energy use and the relative carbon emissions, embodied energy (and carbon emissions) becomes more important (Ibn-Mohammed et al. 2013). Moreover, other categories of environmental pressure exist such as acidification or ozone layer depletion, and these should be considered as well as global warming (Rockstrom et al. 2009; Burger et al. 2009).

In response to these particular issues and to the wider sustainability dilemma, a number of political and environmental activists have been advocating the use of ‘alternative’ products, locally
manufactured and based on renewable resources, in the built environment as well as in the other sectors of the economy. Theoretical approaches such as ecological economics (Veen-groot and Nijkamp 1999), bioregionalism (James and Cato 2014) and localisation (Frankova and Johannisova 2011; Hines 2014; Erickson et al. 2013; North 2010) argue that substantial benefits could be gained in environmental, social and economic terms if more sustainable products are used:

- Products based on renewable resources, namely biomass, are considered to have lower environmental impact than products based on mineral and fossil resources, due to the differences in raw materials and production processes.

- Local manufacturing is considered to reduce environmental impact, due to fewer emissions from transportation, and to have a positive effect on the local economy and society, due to business development and job creation.

It is reasonable to question to what degree it is actually possible substituting the current building products with viable alternatives. It can be argued that technical constraints, for example the need for high tensile strength or fire protection, can pose limits to product substitution, as well as constraints related to the effective capacity of the local natural resources of sustaining a high supply of materials. Moreover, there is need for evidence that product substitution at a large scale could provide significant benefits and offsets any potential negative impacts.

Within the search for more sustainable building products, several studies and Life-Cycle Assessments (LCA) have been conducted on thermal insulation products based on mineral, fossil or biomass materials (Anastaselos et al. 2009; Zhou et al. 2010; Murphy and Norton 2008; Kymäläinen and Sjöberg 2008; Schmidt et al. 2004; Asdrubali et al. 2015; Jagruthi et al. 2014; Densley Tingley et al. 2015; Mazor et al. 2011; Intini and Kühtz 2011; Pargana et al. 2014). Insulation products are essential materials for energy efficiency in buildings, and their overall life-cycle balance is generally positive at least in term of carbon emissions, as the emissions avoided through adequate thermal insulation of buildings largely offset the emissions caused by the production of insulation products. Two reasons can be found for the interest of researchers towards LCA of insulation products:

- There is a large number and variety of products on the market, thus research in this field reflects on the differences in embodied impact associated to the use of different primary materials (biomass, mineral or fossil) and manufacturing processes (Huijbregts et al. 2003);

- The demand for thermal insulation products can be expected to rise, due to the necessity to increase energy efficiency in buildings, and therefore their environmental and socio-economic impact could become more relevant.

**Research aim**

Most LCA studies on insulation products are conducted at a small scale, comparing a few products for a specific purpose (Schmidt et al. 2004; Densley Tingley et al. 2015; Intini and Kühtz 2011; Murphy and Norton 2008). This research takes a different approach, looking at product substitution at the regional scale over a period of 35 years. The aim is to estimate the environmental impact of a progressive increase in the use of local biomass-based insulation products, considering the benefits and trade-offs caused by substitution and the natural resource capacity to supply the necessary materials.

Wales is an ideal case study for this research due to its clear regional identity, the potential of its natural resources and the ambition towards a more sustainable development embedded in its legislative framework (Welsh Government 2009) together with the need to increase the efficiency of its dwellings in order to reduce fuel poverty. This research is part of a larger work, which includes the demand for insulation from renovated dwellings and enlarges the traditional LCA approach to include socio-economic indicators based on input-output analysis. The research looks for quantitative evidence on whether or not the claimed benefits of local biomass products could justify the effort
towards a progressive substitution of the conventional products, but it does not investigate how this substitution could be achieved in terms of policy choices.

### Research scope and context

The scope of this paper is limited to the demand expected to arise from new domestic buildings, and specifically to the demand for thermal insulation of external walls, roofs and ground floors. Five conventional products are considered, which cover the large majority of the market, and two ‘alternative’ products, based on biomass which can be ‘farmed’ and processed in Wales. Other types of insulation products, for example vacuum panels, are available on the market, although their penetration is limited due a series of technical and economic reasons, which are not discussed here. The impact of these products is not considered in this research, but their share of the market is taken into account. The seven types of products considered in this paper are as follows:

---

### Mineral products

1. Stone wool;
2. Glass wool;

Both stone wool and glass wool are fibrous materials obtained melting a mix of igneous rocks and industrial waste and spinning it into filaments. The latter are compressed and bound with a resin (usually urea-formaldehyde), and cut into mats or slabs. Additives are often used to ensure chemical and fire retardant properties (European Insulation Manufacturers Association 2012).

### Fossil-based products

3. Polyurethane Rigid foam (PUR);
4. Expanded Polystyrene (EPS);
5. Phenolic foam;

Polyurethane and phenolic rigid foams are thermoset plastic polymers obtained through several chemical processing of hydrocarbons, thus the raw materials are oil and natural gas (Institut Bauen und Umwelt 2014). Most products are finished with additives and metal or mineral fibre facings to ensure chemical and fire retardant properties (Federation of European Rigid Polyurethane Foam Association 2006). Expanded polystyrene is also a plastic polymer, although it is obtained through different processes and its last stage consists in expanding polystyrene beads through a blowing agent (PWC 2011).

### Biomass-based products

6. Hemp Fibre (HF);
7. Sheep Wool (SW).

These two types of insulation products are available on the UK market and they can be identified as adequate candidates for biomass-based production in Wales:

- Besides the evidence of historical production of hemp in Wales, research has shown that industrial hemp (the primary material for HF insulation) can be grown in the region thanks to its limited requirements (Henfaes Research Centre, 2005; Murphy and Norton 2008).

- In regard to sheep wool, its production in Wales is well-established due to the historical as well as contemporary importance of sheep raising in the Welsh economy and culture. The logistics of regional production and the innovative use of sheep wool as low-carbon material have also been the subject of research (Morris, 2013; Murphy and Norton 2008).

Besides HF and SW, a number of other types of biomass-based insulation products exist (for example, flax or wood fibre) and innovative products based on recycled materials (for example, polyethylene
fibres) are also becoming available on the market. These products could also be employed to substitute the conventional ones, however this research focuses on HF and SW products because of their strong connection to Wales.

Generally it is more correct to say that HF and SW products, at least in their present commercial forms in Europe, are mostly biomass-based, as insulation mats and rolls made with hemp fibre or sheep wool contain about 15% of polyethylene fibres, for binding and ensuring stiffness, and additives to ensure chemical and fire retardant properties (Murphy and Norton 2008). However, the raw materials of the two products are very different:

- Industrial hemp fibres are obtained by processing hemp straw (van der Werf 2004), which and are already used in commercial applications to produce biomass-based plastic (Rosa et al. 2013; Bath and Carus 2015). The term ‘industrial’ hemp is used to indicate a variety of the plant that has no effective potential to be used as a drug, and its cultivation for commercial purposes is licensed in the UK by the Home Office.

- Sheep wool used in insulation products is generally of lower visual and tactile quality in comparison to wool used for clothes, but it has essentially the same insulating properties. Wool is a natural ‘product’ of sheep, which need to be sheared to maintain the health of the animals. In the past of the UK many sheep were raised mainly for wool production, but in the current situation the large majority of sheep are raised for meat production, and wool is considered a by-product (Wiedemann et al. 2015).

Both hemp fibre and sheep wool are often considered ‘sustainable’ materials due to their natural origins and, more importantly, to their carbon sequestration, namely their capacity to absorb carbon from the atmosphere and store it in their chemical structure, thus contributing positively to limit global warming (Murphy and Norton 2008). On the negative side, it must be noted that any intensive agricultural activity and sheep farming in particular, can cause types of pollution which are different from carbon emissions but should not be dismissed, such as for example acidification and eutrophication.

The seven types of insulation products considered in this research have different physical properties, the most relevant are density and thermal conductivity, which are required to calculate quantity and environmental impact of each product. Typical values used in this research are shown in Table 1. Besides the price, the weight and the capacity to insulate, also moisture absorption, stiffness and compressive strength play a role in product choice for specific applications.

<table>
<thead>
<tr>
<th>Product</th>
<th>Density (kg/m³)</th>
<th>Thermal conductivity (W/mK)</th>
<th>Weight (kg) of functional unit of 1 m² with R-value=1 m²K/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Stone wool</td>
<td>41</td>
<td>0.035</td>
<td>1.435</td>
</tr>
<tr>
<td>2 - Glass wool</td>
<td>23</td>
<td>0.04</td>
<td>0.92</td>
</tr>
<tr>
<td>3 - PUR</td>
<td>32.7</td>
<td>0.022</td>
<td>0.719</td>
</tr>
<tr>
<td>4 - EPS</td>
<td>15</td>
<td>0.036</td>
<td>0.54</td>
</tr>
<tr>
<td>5 - Phenolic</td>
<td>35</td>
<td>0.031</td>
<td>0.735</td>
</tr>
<tr>
<td>6 - Hemp fibre</td>
<td>35</td>
<td>0.039</td>
<td>1.365</td>
</tr>
<tr>
<td>7 - Sheep wool</td>
<td>25</td>
<td>0.039</td>
<td>0.975</td>
</tr>
</tbody>
</table>
Methodology

The method adopted in this research combines two techniques: (1) the development of supply scenarios and (2) the evaluation of their environmental impact through LCA categories. The potential benefits and trade-offs of the progressive product substitution are evaluated comparing the environmental impact of six alternative supply scenarios to a baseline supply scenario. The latter is based on a business-as-usual approach, assuming that the future demand for insulation products will be met with the same products currently dominating the market. The six alternative scenarios are based on variations of the extent of the product substitution.

The demand for insulation from new dwellings in Wales from 2016 to 2050 has been previously quantified by the author in square meters of insulation with a thermal resistance (R-value) of 1 m²K/W. This estimate is based on the assumption of a low but steady growth in the domestic market and of an increase in the quantity of insulation required by Building Regulations. The full results of the study are in the process of publication (Varriale 2016).

Scenario building

The baseline supply scenario is shown in Figure 1. A fraction (10%) of the future market is assumed to be taken by ‘other products’, in order to take into account products which are not among those considered in this research. The sharp rise in demand in the years 2020-2022 reflects the key assumption of a tightening of the maximum U-values required by Part L of the Building Regulations in Wales (Welsh Government, 2014a), from the current requirements of:

- 0.21 W/m²K for external walls;
- 0.15 W/m²K for roofs;
- 0.18 W/m²K for ground floors;

These values are compared to the levels of the Passivhaus standard, which requires:

- 0.15 W/m²K for external walls;
- 0.15 W/m²K for roofs;
- 0.15 W/m²K for ground floors.

Although this change in Building Regulation can only be assumed as a future option, it is arguably an essential policy choice in order to ensure high levels of energy efficiency in new dwellings.

The percentages of the five conventional products and the ‘others’ have been established considering the accessible sources (Dunster 2007; Purple Market Research 2009; Office for Fair Trading 2012; AMA 2015). This data shows that until recent years mineral products (Stonewool and Glasswool) had a larger presence on the market (about 50%), although in the last year Polyurethane products (PUR) have increased their share considerably. It must be also mentioned that the most recent estimates of the UK insulation market (AMA Research 2105) reports market share in terms of value (£), therefore it was necessary to operate a conversion into physical quantity (m² with R=1 m²K/W) through average price values for each building product.

The baseline scenario projects the current market share in the future and potential changes are not taken into account. Although the resulting figures are a rough estimate of the future market product mix, the aim of this research is to evaluate the impact of some of these potential changes, and therefore a business-as-usual scenario is necessary in order to have a baseline against which alternatives can be compared. Further steps beyond the scope of this paper will inquiry the effects of changes in the product mix of the baseline supply scenario.
The chosen alternative scenarios are based on different assumptions, shown in Table 2, in regard to two main variables, which are used to determine the level of substitution that the biomass-based products can achieve. The first variable is the ‘peak substitution’, namely the maximum share of the market that HF and SW insulation achieve in combination. The second variable is the ‘internal mix’ of HF and SW, and accounts for the possibility of an equal market share of the two products or the predominance of one over the other.

The yearly percentages of progressive substitution are determined using a ‘bell curve’ starting at 1% substitution in 2016 and reaching its peak in 2040, and from 2041 to 2050 the share is maintained constant (Figure 2). The choice of a bell curve do describe the uptake of alternative products follows the theoretical model on the diffusion of innovations by Rogers (2003). The first three alternative supply scenarios take a more conservative stance assuming a 25% of peak market share for biomass-based products, which determines a total substitution of 16% over the period 2016-2050. The other three scenarios assume a higher success of the biomass-based products, reaching 50% of the market and a total substitution of 33%.

Table 2 - Matrix of 3x2 variables generating the six alternative supply scenarios.

<table>
<thead>
<tr>
<th>Internal mix</th>
<th>Hemp fibre 50% Sheep wool 50%</th>
<th>Hemp fibre 25% Sheep wool 75%</th>
<th>Hemp fibre 75% Sheep wool 25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak substitution at 25% (16% total)</td>
<td>Alternative supply scenario A.1</td>
<td>Alternative supply scenario A.2</td>
<td>Alternative supply scenario A.3</td>
</tr>
<tr>
<td>Peak substitution at 50% (33% total)</td>
<td>Alternative supply scenario A.4</td>
<td>Alternative supply scenario A.5</td>
<td>Alternative supply scenario A.6</td>
</tr>
</tbody>
</table>

Figure 1 - Baseline supply scenario to meet the future demand for domestic thermal insulation in Wales ($m^2$ with $R=1 \text{ m}^2\text{K/W}$).
The environmental impact considered in this paper is limited to the life-cycle stages that occur before the installation of products in buildings, namely resource extraction, manufacture and transport up to the construction site, which correspond to the ‘cradle-to-site’ boundary definition and to stages A1 to A4 in the widely referenced CEN/TC350 framework (AFNOR 2012; Wittstock et al. 2011). The cradle-to-site boundary can be divided into ‘cradle-to-site’, which accounts for extraction, manufacture and the transportation in between, and ‘gate-to-site’, which accounts only for the last stage of transportation.

The environmental impact is assessed through five impact categories, used in most LCA studies (Anderson and Thornback 2012). Other environmental impact categories exist, but the scarce availability of LCA data and the necessity to keep the research within manageable limits restricted the choice to the five described here:

- **Primary Energy (PE)**: this category accounts for the energy (from renewable and non renewable sources) used for the extraction, processing and transportation of materials, not including the energy potential of materials used as primary resources. Although energy use in itself does not directly cause environmental impact, the amount of energy embodied in a product, apart from having economic significance, is considered a good proxy for the overall environmental ‘intensity’ of its production process.

- **Global Warming Potential (GWP)**: this category accounts for the carbon dioxide and other Greenhouse Gases (GHG) emitted during the extraction, processing and transportation of materials. The atmospheric concentration of GHG is related for the increase of the radiative forcing of the atmosphere which causes global climate change.

- **Acidification Potential (AP)**: this category accounts for the acid gases emitted during the extraction, processing and transportation of materials. These substances can damage ecosystems through the phenomenon commonly known as ‘acid rains’.

- **Eutrophication Potential (EP)**: this category accounts for the nitrates and phosphates released during the extraction, processing and transportation of materials. Excessive concentration of these substances in waters leads to ecosystem imbalance and damage.
Photochemical Ozone Creation Potential (POCP): this category accounts for specific pollutants, such as nitrogen oxides, emitted during the extraction, processing and transportation of materials. High concentration of these pollutants causes the creation of ozone in the low atmosphere, where it has negative effects on ecosystems and human health.

The product LCA were conducted for a functional unit of 1 m$^2$ of insulation with R-value=1 m$^2$K/W. The cradle-to-gate impact of the stone wool (1), glass wool (2), PUR (3) and EPS (4) was assessed using the aggregated life-cycle inventories (LCI) contained in the Educational version of the GaBi database (GaBi 2015). The aggregate nature of these LCI did not allow choosing the energy mix or changing other parameters, however they are relevant for British or at least European conditions. No LCI was available for phenolic foam products (5), thus the results of an Environmental Product Declaration (EPD) were used (Institut Bauen und Umwelt 2014). The impact of the gate-to-site transportation was calculated with the GaBi database considering that 90% of products manufactured in the UK and the rest are imported, as indicated in (Office for Fair Trading 2012). For imported products a total of 450 km by truck and 500 km by ship are assumed, whilst for m domestic products only 250 km by truck are considered.

The LCA results for a functional unit of 1 m$^2$ with R=1 m$^2$K/W are shown in Figures 2 to 6, which allow comparison of the five conventional products on the basis of their insulating capacity. For all products apart from phenolic foam (5) it was possible to benchmark the resulted impact against other LCAs for similar products. By collecting the results of existing LCAs contained either in academic studies or EPD, it was possible to identify the ranges indicated in Figures 2 to 6 by taking the average and standard deviation for each impact category. However, a few caveats need to be mentioned in order to avoid taking these benchmarking ranges too strictly:

- Although the sample of LCAs is the result of an extensive search, there might be other studies that have not been accessible, and the number of LCAs identified is too small (15 cases) to provide an adequate population for a reliable statistical analysis.
- Several of these LCA studies are limited to the cradle-to-gate boundary and therefore do not include the last stage of transportation; however the results show that the impact of this stage is very limited.
- Most of these LCA studies make use of functional units based either on thermal resistance (as this research) or on mass, and the transition from one to the other (necessary for comparison) needs to assume typical density and/or thermal conductivity, when these values are not declared in the study. Although the variation of density and/or thermal conductivity for each product in most cases is limited, this estimation process introduces an additional level of uncertainty.

Figures 3 to 7 show that the product with highest impact in 4 out of 5 categories is Rigid Polyurethane foam (3-PUR), excluding in the POCP category where EPS (4) displays the highest impact by far.
Figure 3 - Cradle-to-site primary energy use of the five conventional products.

Figure 4 - Cradle-to-site global warming potential of the five conventional products.
Figure 5 - Cradle-to-site acidification potential of the five conventional products.

Figure 6 - Cradle-to-site eutrophication potential of the five conventional products.
The cradle-to-gate impact of the two biomass-based products was assessed using the LCI by Norton (2008), who studied cradle-to-gate processes of one HF and one SW UK-based product in detail. These LCI have been modified with data from different sources (Bath and Carus 2015; Skowrońska and Filipek 2014; van der Werf 2004; Wiedemann et al. 2015; Williams et al. 2006) to take into account modifications, of which the most important are:

- the assumption that the manufacturing process of the HF takes place in Wales, and not in France as it is currently the case;
- the inclusion of a fraction of the environmental impact of sheep farming in the LCI of the SW product. This process, called ‘allocation’ in LCA terminology, was done on an economic base, considering the average prices of wool and sheep meat in Wales. Norton (2008) illustrated that the impact of sheep farming was attributed entirely to meat production, allowing the SW product to obtain a very low impact. However, the results of this study show that even if a small fraction (2%) of the sheep farming impact is allocated to wool, the environmental pressure attributed to SW insulation becomes more prominent. The LCA results for the five impact categories for the lamb meat were calculated using the ‘Agri-LCA’ model developed by Cranfield University (Williams et al. 2006).

The results of the LCAs conducted for the two biomass-based products are shown in figures 8 to 12. Few LCAs on HF and SW insulation have been conducted (Oekobau 2013; Norton 2008; Zampori et al. 2013; IBO 2015), and these show substantial differences in the methods adopted for allocation and carbon sequestration. In order to maintain the focus of this paper, it was decided not to include the benchmarking ranges for these products. The environmental impact resulting from the cradle-to-gate period is broken down into three stages:

- Farming, namely hemp farming for HF insulation and sheep raising for SW insulation;
- Manufacture, namely all the processes from the raw materials to the finished products and
- Gate-to-site, namely the last stage of the transportation.

This division allows considering the contribution of the ‘extraction’ of the biomass to the overall impact, ad to confirm the limited impact of transportation. Figures 8 to 12 suggest that for HF
insulation, the farming stage has little impact in most categories and even a considerable ‘negative’ impact for GWP, showing that the carbon sequestered in the plant is capable of offsetting the carbon emitted during the manufacture stage. It must be mentioned that because the hemp shives produced together with the fibres have economic value, 53% of the environmental impact of the farming stage is allocated to the shives, and therefore not accounted in the HF impact. The figure is based on data from Norton (2008) and Carus et al. (2013).

By allocating a small fraction of the sheep farming impact to the wool, the SW insulation proved to have significant effects in all impact categories but primary energy. In fact, Figure 9 shows that the carbon sequestered in the wool structure is not enough to offset the GHG emissions resulting from sheep raising. Figures 10 and 11 indicate that in the acidification and eutrophication potentials allocated to raw wool are considerably larger than what can be attributed to the manufacture stage. Only in the POCP category the contribution of the farming stage actually decreases the overall impact. This positive effect can be traced back to the sheep raising impact as modelled in AgriLCA (Williams et al. 2006).

Figure 8 - Cradle-to-site primary energy use of hemp fibre and sheep wool insulation.

Figure 9 - Cradle-to-site global warming potential of hemp fibre and sheep wool insulation.
Figure 10 - Cradle-to-site acidification potential of hemp fibre and sheep wool insulation.

Figure 11 - Cradle-to-site eutrophication potential of hemp fibre and sheep wool insulation.
Results and discussion

Baseline supply scenario

Figure 13 shows the environmental impact assessed for the baseline supply scenario. The absolute figures of each impact category have been normalised using Western European factors from CML 2001 (Huijbregts et al. 2001). Normalisation is an LCA procedure which allows comparison of the impact categories with each other. By dividing the absolute figures of each impact category by the corresponding impact of an average Western European citizen, the resulting unit-less figures can be used to evaluate the relative importance of each impact category. In the context of this method, Figure 13 clearly indicates that the impact of the baseline supply scenario is most relevant for Primary Energy use and least relevant for Eutrophication potential.

Looking at the contribution of each product type to the overall impact (Figure 14), it can be noted that the largest impact except in the POCP category is attributable to Polyurethane (3-PUR). This is because PUR is the most polluting product according to the LCA results (Figures 3 to 7) as well as the most preferred product in the market mix represented in the baseline supply scenario (Figure 1).
Alternative supply scenarios

Figure 15 shows the product distribution assumed in the alternative scenario A1, considering 25% of peak substitution and an equal share of HF and SW products. In comparison to Figure 1, it can be seen that the progressive increase in the use of biomass-based products up to 25% in 2040 actually allows the conventional products to maintain a roughly constant volume of use. This happens because assuming a steadily growing domestic market and an increase in the U-value requirements of UK Building Regulations, the insulation market expands and therefore a moderate uptake of alternative products does not necessarily mean that companies producing conventional ones will see a decrease in sales.
Figures 16 to 20 compare the environmental impact of the alternative scenario A1 to the baseline scenario. Moderate reductions can be noted in the categories of Primary Energy, GWP and POCP, whilst Acidification and especially Eutrophication potential are increased. These negative effects can be clearly attributed to the impact of sheep wool insulation, and more specifically to the effects of sheep raising (see Figures 10 and 11) which by itself doubles the Eutrophication potential (Figure 19).

Figure 15 - Product distribution in the alternative scenario A1 for the future supply of domestic thermal insulation in Wales (m² with R=1 m²K/W).
Figure 16 - Comparison between the total primary energy use of the baseline and of the alternative supply scenario A1.

Figure 17 - Comparison between the total global warming potential of the baseline and of the alternative supply scenario A1.
Figure 18 - Comparison between the total acidification potential of the baseline and of the alternative supply scenario A1.

Figure 19 - Comparison between the total eutrophication potential of the baseline and of the alternative supply scenario A1.
The alternative scenarios and the baseline are compared by looking at the normalised results (Figure 21), which shows that the positive and negative savings achieved with the 25% peak substitution are accentuated with peak substitution at 50%. In all alternative scenarios, positive savings (a decrease in the impact) are achieved in the categories of PE, GWP and POCP, whilst negative savings are achieved in AP and EP. While in percentage terms the negative savings are much higher than the positive ones, it can be noted that the normalised results indicate that EP is the least important impact category. Moreover, alternative scenarios where hemp is preferred over sheep wool show much smaller increases in AP and EP. This is consistent with the high impact of sheep wool shown in Figures 8 to 12 and 16 to 20, and therefore it can be argued that scenarios with higher quantities of HF over SW products should be preferred in order to limit the increase in AP and EP.

It should be noted that the environmental impact caused by sheep raising, which is partially allocated to the wool and contributes significantly to the overall impact of the SW product, takes place independently from how the wool is used, and would happen in any case due to raising sheep for meat production. Therefore another question that should be posed is whether using low quality wool to produce insulation products can be considered having less or more of an impact than present commercial applications, such as floor carpeting. This question is beyond the scope of this paper, but as insulation products save large amounts of operational energy and GHG emissions, there could be a strong argument in favour of increasing the use of sheep wool for building insulation.
The final step of this paper looks at the demand for resources that the alternative supply scenarios would pose to the Welsh environment. In Table 3 the lowest and highest annual demands for hectares of hemp harvest (for HF insulation) and for kilograms of raw ‘greasy’ wool (for SW insulation) are compared to statistical values that can be used as indicators of the supply capacity of Welsh resources. From these figures, it can be observed that both HF and SW products in the cases of lowest demand could easily be provided for in Wales. In the case of highest demand, although this is still below the volumes of total production, the supply of HF and SW products entirely from Welsh resources seems less feasible, because the necessity to use biomass for insulation would subtract significant resources from other products. However, while in recent years the amount of Welsh land classified as agricultural has increased significantly (+38% in 2013 in comparison to 2008), the amount of raw wool produced in Wales has declined (-23% in 2013 in comparison to 2004). Therefore, it can be argued that the regional potential to supply hemp fibre for insulation products is higher than the potential to supply raw wool.
Table 3 - Comparison between the minimum and maximum peak demands for raw materials of the alternative insulation products and indicators for the supply capacity of the related natural resources of Wales.

<table>
<thead>
<tr>
<th>6 - Hemp fibre</th>
<th>Max annual demand for hemp harvest</th>
<th>% of average (2006-2013) agricultural land in Wales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest demand</td>
<td>Alternative supply scenario A2</td>
<td>437 hectares</td>
</tr>
<tr>
<td>Highest demand</td>
<td>Alternative supply scenario A6</td>
<td>2,620 hectares</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7 - Sheep wool</th>
<th>Max annual demand for raw wool (kg)</th>
<th>% of average (2004-2013) raw wool produced in Wales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest demand</td>
<td>Alternative supply scenario A3</td>
<td>626,002 kg</td>
</tr>
<tr>
<td>Highest demand</td>
<td>Alternative supply scenario A5</td>
<td>3,756,013 kg</td>
</tr>
</tbody>
</table>

Overall, the results of this paper suggest that among the two biomass-based products, Hemp Fibre is preferable to Sheep Wool due to lower environmental impact and smaller demand of natural material in comparison to the capacity of Welsh resources. Therefore scenario A.3 is probably the most favourable among the investigated options:

- The environmental impact of the supply of insulation products would decrease in the categories of Primary Energy (about -6%), GWP (about -18%) and POCP (about -15%), while increasing in the least important category of Eutrophication (about +40%);

- A moderate but steadily rising market share (reaching 25% in 2040) of biomass-product could allow the producers of conventional products to retain their current volumes, limiting the impact of product substitution on other industries. This is valid within the assumptions of a steady growth in domestic building demand and an increase in the U-value requirements of the Buildings Regulations.

The argument for implementing a moderate but nonetheless significant increase of biomass-based products should be weighted against the economical, legislative and logistical limits imposed by the present situation. Currently, biomass-based insulation products are generally more expensive than conventional ones, due to higher production costs. This can be attributed to higher costs for raw materials and manufacturing process, but also to the absence of a larger infrastructure capable to reduce costs through economies of scale. At the moment, Wales is lacking local manufacturers of biomass-based products capable to meet a potential rise in the future demand at the regional scale such as modelled in this research. The establishment of a regional cluster of manufacturers in reply to this demand could have significant positive effects on the local economy.

Within the legislative context, the current Building Regulations do not really acknowledge the benefits of building products with lower embodied impact. Since control of the Building Regulations has been recently devolved to Wales, local policy-makers have the opportunity to influence the market for...
thermal insulation products by progressively tightening the U-value requirements and inserting criteria to take into account the embodied impact of products.

**Research limitations**

The limitations of this research can be considered typical of the adopted techniques, namely scenario-building and LCA:

- Both baseline and alternative supply scenarios consider a limited number of insulation products, although these products cover the large majority of the current market;
- The share of each product type adopted in the supply scenarios is the result of reasonable assumptions on the available UK data, but does not reflect any possible specific feature of the Welsh market, due to lack of data;
- There can be significant variations in the values of density, thermal conductivity and environmental impact even among products of the same type.
- The available normalisation factors (Huijbregts et al. 2003) are rather outdated (1995 data), and the method is somehow questionable, as it refers to the existing environmental impact levels (which might already be excessive) and not to a set of environmental thresholds such as, for example, the concentration of GHG in the atmosphere.
- Process-based LCA can be very detailed but present risk underestimating the indirect impacts. The LCI for used to assess the SW product in this paper is missing to account for the impact from the treatment of the wastewater from the ‘scouring’ (cleaning) of the raw wool.

**Conclusion**

This paper has presented different supply scenarios in order to evaluate the environmental impact of substituting five types of conventional thermal insulation products for new dwellings with two alternatives which are generally perceived as more sustainable. Considering five environmental impact categories, six alternative supply scenarios were compared to a baseline scenario based on a business-as-usual market share, a steady domestic market growth and an increase in the U-value requirements of the Buildings Regulations.

- The baseline results show that the large use of PUR products causes the majority of environmental impact in all categories except POCP, where the effect of EPS is bigger.
- Moderate reductions can be achieved in the categories of Primary Energy, GWP and POCP although increments occur in the categories of Acidification and especially Eutrophication Potential. However, EP is also the least important impact category if the average impact of Western Europe is considered through normalisation.
- Since the Hemp Fibre (HF) product displays a better environmental performance than Sheep Wool (SW), in alternative supply scenarios where HF has a larger market share than SW the increments in AP and EP are more limited. However, the increments in AP and EP due to the SW product are entirely attributable to the fraction of the sheep raising impact allocated to the insulation product, and therefore should be considered in a wider context.
- Finally, the maximum annual demand for biomass resulting from the alternative supply scenarios were compared to indicators of the supply capacity of Welsh resources, concluding that a moderate increase in the use of SW and especially HF could be sustained entirely with biomass sourced in Wales.

With regard to future research, the results of this paper will be integrated and extended in the PhD of the author. A series of sensitivity analyses will be conducted on the share of products contained in the supply scenarios and on the LCA results, especially those of the alternative products in order to understand better the effect of allocation choices. Further and more detailed considerations will be
made on the effects of sourcing the necessary biomass for the alternative products in Wales and of shifting biomass resources from one production to another. The criteria for the evaluation of the supply scenarios will be increased to include issues of human health and socio-economic indicators considering product prices, value added and job generation.

References


From energy behaviours to energy resources optimisation in smart(er) grids: development of an energy management system

Marta A.R. Lopes 1,2, Ana Soares 2, Carlos Henggeler Antunes 2,3, Álvaro Gomes 2,3

1) Dept. of Environment, ESAC - Polytechnic Institute of Coimbra, 3045-601 Coimbra, Portugal
2) INESC Coimbra, Rua Antero de Quental 199, 3000-033 Coimbra, Portugal
3) Dept. of Electrical and Computer Engineering, University of Coimbra, 3030-290 Coimbra, Portugal
Corresponding authors: Marta Lopes, mlopes@esac.pt; Ana Soares, argsoares@inescc.pt

Abstract: In smart grids end-users are expected to be increasingly involved in the management of energy resources, namely planning their electricity usage according to their needs and the economic incentives provided (e.g., by shifting appliance operation to profit from time-of-use tariffs), generating electricity using renewable sources, and storing or trading electricity generated on-site. However, deciding whether to use, store or sell electricity back to the grid in face of dynamic variables (e.g., tariffs, comfort requirements, weather conditions also with impact on generation availability) is a very challenging decision process for end-users, namely in a residential or small business setting, thus requiring some form of automated support. Therefore, energy management systems (EMS) are required to monitor consumption, generation and storage, and to optimise decisions according to input signals and end-users’ needs and preferences. This paper outlines the development of an EMS to manage in (near) real time energy usage in the residential and small business sectors. The EMS is endowed with algorithms to coordinate the energy demand, storage, local generation and exchanges with the grid according to price signals, comfort requirements, weather conditions and renewables availability. In addition to incorporating load characteristics and technical constraints into the optimisation process, end-users’ preferences regarding usage patterns, daily activities and energy behaviours are elicited.

Introduction

The evolution towards smart regions is in the critical path of the decarbonisation of the economy. This transition comprises the deployment of smart grids, in which decentralised renewable energy resources are combined with existing energy generation, storage systems (including electric vehicles) and controllable demand aiming at the integrated optimisation of all energy resources (OECD/IEA, 2011, EC, 2011, Hledik, 2009, EC, 2013). End-users play a relevant role in this process and the development of “integrated, affordable and user-friendly multi-optimised solutions” is considered essential to promote end-use energy efficiency as a step towards more efficient buildings, smart regions and communities (EC, 2013).

In smart grids end-users are expected to be increasingly involved in the management of their energy resources, namely planning their electricity usage according to their needs and the economic incentives provided (e.g., by shifting appliance operation to profit from time-of-use tariffs), generating electricity using renewable energy resources, and storing or trading electricity generate on-site (Lopes et al., 2016). However, deciding whether to use, store or sell electricity back to the grid in face of dynamic variables (e.g., tariffs, comfort requirements, weather conditions also with impact on generation availability) is a very challenging decision process for end-users, namely in a residential or
small business setting, thus requiring some form of automated support (Livengood and Larson, 2009, Lopes et al., 2012, Chassin, 2010, Soares et al., 2014a). Therefore, energy management systems (EMS) are required to monitor consumption, generation and storage, and to optimise decisions according to input signals and end-users’ needs and preferences.

Most studies on EMS use engineering modelling approaches to optimise, in simulated settings, end-users’ decisions regarding the management of energy resources. Specific appliances, such as thermostatically controlled loads (e.g., air conditioning systems, electric water heaters) are often considered in the optimisation process (Schweppe et al., 1980, Mohsenian-Rad and Leon-Garcia, 2010, Ericson, 2009, Du and Lu, 2011). Nonetheless, other loads in the residential setting may also be managed, such as cold appliances (e.g., refrigerator, freezer), the laundry machine, the tumble dryer, and the dishwasher (Soares et al., 2014c). The optimisation process incorporated in EMS usually aims to minimise the electricity bill using kWh market prices (Soares et al., 2013, Zhuang et al., 2013, Salinas et al., 2013), considering grid constraints (Yao et al., 2005), users’ preferences (e.g., load control, prices) and other technical restrictions (Molderink et al., 2012). Optimisation approaches embedded in EMS are diverse and include evolutionary algorithms (Soares et al., 2013, Allerding et al., 2012, Zhuang et al., 2013, Salinas et al., 2013, Soares et al., 2014a, Logenthiran et al., 2012, Yao et al., 2005), linear programming (Conejo et al., 2010, Gang et al., 2011, Molderink et al., 2012), convex programming (Tsui and Chan, 2012), game theory (Mohsenian-Rad et al., 2010), dynamic programming (Livengood and Larson, 2009), tabu search (Abras et al., 2008) and other meta-heuristics such as particle swarm optimisation (Pedrasa et al., 2010, Gang et al., 2011, Kahrobaee et al., 2013).

In the development of EMS, simulated circumstances about end-users’ preferences and their daily activities are usually assumed to provide general estimates of technical and economic potential. Instead, this work uses a multidisciplinary approach, integrating expertise from the social sciences with engineering, to develop a systemic perspective and more accurately elicit end-users’ daily activities, needs and preferences to build an EMS able to manage energy usage in near real-time. The EMS is endowed with an evolutionary algorithm to coordinate energy demand, storage, local generation and exchanges with the grid according to price signals, comfort requirements, weather conditions and renewables availability. Evolutionary algorithms are especially adequate to cope with the combinatorial nature of the problem and multiple objective functions to assess the quality of solutions, while requiring mild computational requirements once properly tuned. This work aims to answer the following question: what information about households’ characteristics, routines and activities is required to be elicited to adequately design an EMS capable of making the optimal integrated management of energy resources? This work has been developed in the framework of the Suscity project - Urban data driven models for creative and resourceful urban transitions - which aims at promoting urban resource efficiency and economic development with minimum environmental impacts while preserving the levels of the energy system reliability. Accordingly, this work presents a regional perspective on the transition to smart grids occurring in Portugal.

The Portuguese context

The electricity system and retail electricity market of Portugal are currently adapting to a smart grid context thus making this an interesting case study to foresee socio-technical challenges.

A charging network for electric vehicles was implemented in 2010/11 with 1,300 smart charging stations accessible to end-users throughout the country (MOBI.E, 2010), although the ownership rate of electric vehicles is still less than 0.1%, being expected to increase in the next years (MEE, 2014). In 2013 renewable energy sources, including wind and hydro, accounted for 63% of overall electricity production (Pordata, 2015). Smart grid initiatives have been implemented by utilities involving the
deployment of smart meters and EMS, ranging from simple in-house feedback displays to programmable systems with actuation on loads (EC, 2014). However, Portugal has not yet decided in favour of a large-scale smart meter roll-out, thus impairing the European Commission’s 80% target penetration rate by 2020. As a consequence, demand response programmes and direct load control activities in the residential setting have had only an experimental basis with limited results.

The liberalised retail energy market was opened to small end-users in 2006 (residential sector and small and medium companies, with a contracted power lower than 20.7 kVA). Since then, small end-users have had the option of leaving the regulated market and joining the liberalised market by choosing another supplier. A financial stimulus was applied to promote this change: those who remain in the regulated market are subject to tariff increases on a quarterly basis. About 69% of electricity customers have already switched to the liberalised energy market (ERSE, 2015c). While electricity in the regulated market is supplied by one provider (the “last resource” company), in the liberalised market eleven companies are currently operating accredited by the Energy Services Regulatory Authority (ERSE, 2015a). It is expected the regulated market finishes by the end of 2017 (ERSE, 2015c).

Small end-users in both the regulated and liberalised markets may choose among flat, dual, three or seasonal time-of-use tariffs and power between 3.45 and 20.7 kVA according to their needs (ERSE, 2015b). Currently, 82% of small end-users have a flat tariff, while 17% already have either a dual or a three time-of-use tariff (Table 1). The most common contracted power category among end-users from the residential and small services sectors is 3.45 kVA with a 56% share, followed by 6.9 kVA with 25%.

**Table 1 - Small electricity end-users in 2015 (ERSE, 2014).**

<table>
<thead>
<tr>
<th>Contracted power (kVA)</th>
<th>Flat</th>
<th>Dual</th>
<th>Three</th>
<th>Seasonal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.45</td>
<td>1,142,932</td>
<td>69,606</td>
<td>11,150</td>
<td>9,945</td>
<td>1,233,632</td>
</tr>
<tr>
<td>4.6</td>
<td>56,062</td>
<td>25,644</td>
<td>4,200</td>
<td>128</td>
<td>86,033</td>
</tr>
<tr>
<td>5.75</td>
<td>25,318</td>
<td>13,655</td>
<td>2,304</td>
<td>34</td>
<td>41,311</td>
</tr>
<tr>
<td>6.9</td>
<td>390,622</td>
<td>140,876</td>
<td>10,815</td>
<td>13,088</td>
<td>555,402</td>
</tr>
<tr>
<td>10.35</td>
<td>101,272</td>
<td>37,301</td>
<td>3,754</td>
<td>6,676</td>
<td>149,003</td>
</tr>
<tr>
<td>13.8</td>
<td>37,977</td>
<td>18,983</td>
<td>1,895</td>
<td>1,591</td>
<td>60,447</td>
</tr>
<tr>
<td>17.25</td>
<td>10,851</td>
<td>6,661</td>
<td>780</td>
<td>334</td>
<td>18,626</td>
</tr>
<tr>
<td>20.7</td>
<td>43,402</td>
<td>20,982</td>
<td>2,230</td>
<td>1,449</td>
<td>68,063</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,808,436</td>
<td>333,707</td>
<td>37,128</td>
<td>33,245</td>
<td>2,212,516</td>
</tr>
</tbody>
</table>

Due to recent economic restrictions, increase of energy prices or even behavioural changes, Portuguese households’ energy consumption has diminished in recent years. The households’ average primary energy consumption has decreased 17% from 2004 to 2013, from 0.82 to 0.67 toe/household.year (excluding vehicles) (DGEG, 2015). Nonetheless, the residential sector still represents 17% of end-use energy, being the third most energy intensive sector after transports and industry (DGEG, 2014). Electricity is the main commodity utilised by households (43% of their overall energy consumption). In average, households have an yearly consumption of 3,700 kWh: 41% in the kitchen, 33% in other appliances, 14% in lighting, 9% in space heating, and 3% in water heating and space cooling (INE and DGEG, 2011). The adoption of renewable energy sources by households has been an on-going process, with 2% already using solar thermal systems to heat water (INE and DGEG, 2011), and 0.2% producing electricity through the use of photovoltaic micro-generation systems (MEE, 2014).
Therefore, this is an important moment to explore how end-users may influence the deployment of demand response programmes based on the smart grid as a contribution to the design of more effective energy policies and programmes.

**From energy behaviours to energy consumption**

People’s daily activities are very diverse and comprise, in general, gainful work and study, domestic work, meals, personal care, travel, free time and sleep (EC, 2004). Most of these activities are performed at home and involve several processes that activate energy services (some of them energy intensive), such as food preparation, dish washing, cleaning, laundry, watching television, or even reading. These activities and processes may be influenced by the socio-economic environment (e.g., financial constraints) and the household’s socio-demographic characteristics (e.g., composition, stage of life, level of education, income, professional activity, dwelling ownership) and social practices (e.g., time spent at home, lifestyle) (Cayla et al., 2011, Hori et al., 2013). Figure 1 illustrates an average day of Portuguese households according to the main activities.

![Figure 1 – Activities performed in an average day of Portuguese households (INE, 1999).](image)

As a result of daily activities, households feel needs whose satisfaction leads to the activation of energy behaviours in order to provide for energy services (e.g., heating, cooling, lighting or electrical appliances powering) (Figure 2 and Table 2) (Lopes et al., 2015, Hong et al., 2015). Energy resources either from renewable or non-renewable sources (e.g., electricity, gas, fuel) enable energy services thus contributing to fulfil households needs. Needs may also be influenced by the physical environment (e.g., climate) and the building characteristics, particularly in as far as thermal and lighting comfort conditions are concerned.

![Figure 2 – Energy consumption activation chain (Lopes et al., 2015).](image)

<table>
<thead>
<tr>
<th>Energy Service</th>
<th>Need</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial lighting</td>
<td>Provides luminance to support daily activities, complementarily to natural light. It is supported by incandescent lamps (81% households), fluorescent lamps (78%), halogen lamps (22%), and LED (3%) [1].</td>
</tr>
<tr>
<td>Leisure and entertainment</td>
<td>Watching TV, playing or listening to music are deeply incorporated in daily routines of families, and are usually performed after home and family care periods, meals, work time, and before sleeping [2]. Appliances’ ownership rates are: TV 100%, Wi-Fi 36%, DVD player 47%, radio 41% [3].</td>
</tr>
<tr>
<td>Work and study</td>
<td>Active families usually work and study at home, namely qualified professions and students, often using a computer (ownership rate: 59%) [4].</td>
</tr>
<tr>
<td>Food refrigeration</td>
<td>Food refrigeration supports nourishment and cooking and it is widely used. Appliances’ ownership rates are: refrigerator with a small freezing area 58%, combined fridge and freezer 38%, and freezer 48% [4].</td>
</tr>
<tr>
<td>Cooking</td>
<td>Cooking is supported by several appliances such as the microwave (ownership rate of 82%), the stove and oven (66%), electric plate (36%), and an exhausting system (66%) [6].</td>
</tr>
<tr>
<td>Dishwashing</td>
<td>Dishwashing it is still mostly performed by hand, but the dishwasher has an increasing role (ownership rate is 41%) [7].</td>
</tr>
<tr>
<td>Home and personal care activities</td>
<td>Home care activities such as vacuuming and ironing are often performed (ownership of vacuum cleaner is 75% and of iron is 92%) [8]. No data is available on appliances supporting personal care practices.</td>
</tr>
<tr>
<td>Laundry</td>
<td>Using a laundry machine is a deeply embedded practice as the ownership rate of 91% illustrates [1].</td>
</tr>
<tr>
<td>Clothes drying</td>
<td>Clothes drying results from laundry and is still mostly performed without a tumble dryer (ownership of 19%) [9], although it depends on the climate characteristics [9].</td>
</tr>
<tr>
<td>Space heating, cooling and ventilation</td>
<td>This service improves the indoor thermal comfort and is needed depending on the climate characteristics, building insulation and the activities performed indoors. While heating is often performed using independent heaters (61% ownership rate), air conditioning (7%) and open fireplaces (24%), cooling is mostly performed using fans (70%) and air conditioning (26%) [10].</td>
</tr>
<tr>
<td>Heating water</td>
<td>Hot water is mostly used in daily hygiene, cooking and home care activities, and it is heated mostly using gas (90%) and only 4% using electricity [9].</td>
</tr>
<tr>
<td>Mobility</td>
<td>Mobility is a service required in the context of leisure, work or home/personal care. 74% of households have at least, one transport vehicle, which consumes either diesel (64%) or gasoline (36%) [11]. Less than 0.1% of the population owns an electric or hybrid vehicle [1].</td>
</tr>
</tbody>
</table>

Energy services and loads management flexibility

Smart grids offer end-users the adequate context to exploit the flexibility of load usage with the purpose of minimising the electricity bill in face of dynamic pricing, without jeopardising comfort requirements.

In a residential setting, load management may comprise the following possibilities (Soares et al., 2014c):

1. Shifting – Some load usage may be postponed or anticipated according to end-users’ preferences. Examples include: doing the laundry (laundry machine and tumble dryer), dishwashing (dishwasher), water heating (electric water heaters), and charging the electric vehicle;

2. Interruption – Some load usage may be interrupted during short periods of time without decreasing the quality of the energy services provided or damaging equipment. Examples include the refrigeration of food (cold appliances), space heating and cooling (air conditioning systems), water heating (electric water heaters), and charging the electric vehicle;
3. Re-parameterisation – In case of thermostatically controlled loads the thermostat settings may be re-set (with small changes) causing no discomfort to end-users. Examples include the refrigeration of food (cold appliances), space heating and cooling (air conditioning systems), and water heating (electric water heaters);

4. No control – Some load usage cannot be shifted or interrupted since this may cause discomfort to the end-users or perturbation to households’ on-going activities. Examples include lighting, office and entertainment equipment, cooking and home/personal care appliances.

Although energy services and load management flexibility depend on the ownership of appliances, it is also subject to the households’ habits and activities, and their willingness to accept the change of their routines (Grijalva and Tariq, 2011, Lopes et al., 2016, Paetz et al., 2012). This flexibility is also influenced by the households’ willingness to leave load management to automated devices (Karjalainen, 2013) or to the utility through direct load control actions (Lopes et al., 2016). Table 3 illustrates a flexibility assessment of energy services and load management for the Portuguese context. The ownership of appliances influences the type of control actions and the overall demand management potential. Some energy services have a high flexibility potential without requiring the households’ adaptation, although others require the adaptation of households’ routines. Knowing in advance the households’ preferences regarding the load operation periods is then crucial to adequately design demand response actions. Moreover, overriding mechanisms are advisable to enable end-users to regain control over the load operations determined by the EMS. Although the willingness to accept the shifting of some appliances is currently high in some segments of the population because it is already embedded in daily practices (Lopes et al., 2016), other less common actions may require a previous assessment of barriers and the development of adequate strategies to overcome them (e.g., change of temperatures set-points).
Table 3 – Energy services and load management flexibility assessment: an example from the Portuguese reality. Table notes: [1] (DGE/IP-3E, 2004); [2] (INE, 1999); [3] (Lopes et al., 2016); [4] In the absence of a national study, an international one was used, (Pierre et al., 2011).

<table>
<thead>
<tr>
<th>Energy services</th>
<th>Energy services activation</th>
<th>Loads</th>
<th>Management potential</th>
<th>Flexibility potential assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shifting</td>
<td>Interruption</td>
</tr>
<tr>
<td>Laundry</td>
<td>Mostly during the morning or after the lunch period [1]</td>
<td>Laundry machine</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Clothes drying</td>
<td>After doing the laundry</td>
<td>Tumble dryer</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Dishwashing</td>
<td>After meals and mainly in the evening [2]</td>
<td>Dishwasher</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Mobility</td>
<td>Often in the morning and afternoon, being variable during the weekend [3]</td>
<td>Electric vehicle</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Water heating</td>
<td>In the morning, after meals and in the evening [1]</td>
<td>Electric water heater</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Space heating and cooling</td>
<td>When at home, for either heating or cooling, in a non-automated mode [2]</td>
<td>Air conditioning</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Refrigeration of food</td>
<td>Continuously [1]</td>
<td>Cold appliances: fridge, freezer</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

**Elicitation process for designing an EMS**

The elicitation of information necessary to design an EMS aiming to optimise energy resources of small end-users may be carried out by means of the following steps (Figure 3):

1. Assessment of appliances ownership;
2. Assessment of end-users' routines;
3. Assessment of the degree of willingness to accept demand response actions over each appliance;
4. Assessment of end-users' preferences regarding time slots for the operation of shifting loads and temperature set-points for thermostatically controlled loads.
Figure 3 – Flowchart of the elicitation process to design an EMS.

This information may be elicited using social sciences tools (e.g., surveys, interviews) or, in some cases, using advanced data mining and/or signal analysis techniques. While engineering tools may be used to extract appliances’ ownership and end-users’ routines from load diagrams, willingness to accept load management actions and specific preferences concerning these actions may be known when directly performing interviews and/or surveys to end-users. Moreover, the knowledge on end-users’ profiles may help anticipating their preferences and limitations regarding load management actions, therefore reducing the effort during the EMS design process.

Research methods

A bottom-up multidisciplinary approach is proposed to explore the household’s flexibility to demand response actions. Expertise from the social sciences is integrated with engineering to establish a household activity model and more accurately elicit end-users’ daily activities, needs and preferences when developing an EMS able to manage energy usage in real-time. The approach is briefly described as follows.
Design of the household activity model

In the last decade there has been a trend of reduction in size of Portuguese families, which in 2014 reached the average of 2.6 individuals per household (Pordata and INE, 2015a). Although households are still mostly composed by a couple with children (35.8%), families composed by a couple with no children have increased at an average rate of 2.4% a year, and one parent family at 2.9% a year (Pordata and INE, 2015c). Moreover, the birth rate has been continuously decreasing (Pordata and INE, 2015b). Hence, for simplification purposes, a household profile was established representing a family composed by a working couple with a child at school age, accounting for approximately 30% of Portuguese households.

Based on the time-use survey of Portuguese households (INE, 1999, Lopes and Coelho, 2002) a schedule of home activities occurring during a regular working week was established. The main activities considered were: sleeping time (in general, from 11 p.m. to 7 a.m.); personal and family care time; home care activities; making and having meals (e.g., breakfast, lunch, dinner); time at (or going to) work/school; leisure time at home (e.g., watching television, listening to music); and some work developed at home (e.g., through computer usage) (Figure 4). A period of nine hours each working day is considered to be spent at work, school or in transit between them (INE, 1999, Lopes and Coelho, 2002); an outdoor leisure time during the weekend is also considered. Overlapping between activities may also occur and therefore the schedule is globally indicative of the activities performed.

<table>
<thead>
<tr>
<th></th>
<th>Friday</th>
<th>Saturday</th>
<th>Sunday</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td>Family care &amp; meals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>02:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>04:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>08:00</td>
<td>At (and going to/or coming from) work &amp; school</td>
<td>Family care &amp; meals</td>
<td>Family care &amp; meals</td>
</tr>
<tr>
<td>09:00</td>
<td>Home &amp; family care</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12:00</td>
<td>Meals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13:00</td>
<td>Home &amp; family care, leisure</td>
<td>Leisure outdoors</td>
<td></td>
</tr>
<tr>
<td>14:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16:00</td>
<td>Work at home, leisure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18:00</td>
<td>Home &amp; family care</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19:00</td>
<td>Meals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21:00</td>
<td>Home &amp; family care, leisure, sleeping</td>
<td>Home &amp; family care, leisure, sleeping</td>
<td>Home &amp; family care, work at home, leisure, sleeping</td>
</tr>
<tr>
<td>22:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23:00</td>
<td>Sleeping</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4 – Illustrative schedule of home activities during a regular working week.

EMS development

An EMS endowed with an evolutionary algorithm was developed to optimise multiple energy resources, including coordinating energy demand, storage, local generation and exchanges with the grid according to price signals, comfort requirements, weather conditions and renewables availability (Soares et al., 2014b). The EMS aims to assist end-users’ decisions concerning the usage of energy resources in the planning period, so that both the electricity bill and end-users’ dissatisfaction due to
control actions are minimised. The optimisation approach is based on a multi-objective evolutionary algorithm and incorporates specific problem-oriented features (Table 4) providing a set of non-dominated solutions (solutions for which no other feasible solutions exists simultaneously improving all the objective functions, i.e. improving one objective function entails accepting to deteriorate at least another objective function value).

Three shiftable loads (a laundry machine, a tumble dryer, and a dishwasher) and three thermostatically controlled loads (an electric water heater, an inverter air conditioner, and a fridge) were considered as manageable loads, as well as an electric vehicle (EV) operating in grid to vehicle mode (G2V) (Figure 6). One cycle of each load was assumed to be activated during the planning period. The uncontrollable base load was also included in the model according to the profile of activities performed (Figure 4). A local photovoltaic micro-generation system was also considered; the energy locally produced is used for self-consumption and the remainder, if any, is injected into the grid with a revenue of 80% of the kWh buying price (Figure 8). Dynamic tariffs are known in advance and are based on the current Portuguese pricing structure (Figure 7).

Table 4 – Multi-objective problem formulation (Soares et al., 2014b).

<table>
<thead>
<tr>
<th>Objective functions</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Minimisation of the energy bill</td>
<td>The energy bill is determined by the acquisition cost from the grid, subtracting the revenue from injecting energy into the grid and responding to grid signals.</td>
</tr>
<tr>
<td></td>
<td>- Shifting loads to non-preferred time slots</td>
</tr>
<tr>
<td></td>
<td>- Proximity to contracted power threshold</td>
</tr>
<tr>
<td></td>
<td>- Changing temperature set points</td>
</tr>
<tr>
<td></td>
<td>- Not ensuring a minimum state of charge of the EV by the end of the planning period</td>
</tr>
<tr>
<td>2. Minimisation of end-users’ dissatisfaction</td>
<td>Utility functions establish the penalties associated with not meeting end-users’ preferences. Two end-users’ profiles were defined assuming different flexibility preferences, while respecting the household dynamics (Error! Reference source not found.). Demand response actions requiring the change of temperature settings of thermostatically controlled loads, which are different from the normal functioning of these appliances, are penalised using an exponential function.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Constraints</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. End-users’ time slot preferences for allocating shiftable loads</td>
<td>Laundry machine, tumble dryer, dishwasher Electric vehicle in G2V mode</td>
</tr>
<tr>
<td>2. End-users’ temperature range for thermostatically controlled loads</td>
<td>Electric water heater, air conditioning, fridge</td>
</tr>
<tr>
<td>3. Respecting the contracted power threshold</td>
<td>A contracted power of 3.45 kVA was assumed (as 33% of Portuguese small electricity end-users).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technical restrictions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical restrictions are associated with each one of the managed loads and allowable demand response actions.</td>
<td>Laundry machine, tumble dryer, dishwasher</td>
</tr>
<tr>
<td></td>
<td>Thermostatically controlled loads: fridge, electric water heater, air conditioning</td>
</tr>
<tr>
<td></td>
<td>Electric vehicle</td>
</tr>
</tbody>
</table>
Two end-users’ profiles were defined assuming different flexibility profiles, while respecting the household dynamics. While the less flexible profile expects loads to be operated immediately when requesting the service and only allows unnoticeable changes in temperature settings, the more flexible profile is willing to accept the operation of loads in an extended period and a higher range of change in temperature settings. These flexibility profiles are reflected on the available time slots for shifting loads (Figure 5) and the temperature settings of thermostatically controlled loads (Table 5). Reference cases for each flexibility profile were also considered to assess the impacts of load management. In both reference cases no optimising management is performed. Shiftable loads are allocated randomly in the time slots selected by end-users with no dissatisfaction penalty associated; the charging process of the electric vehicle starts immediately when plugged-in by end-users and this process is not interrupted; thermostatically controlled loads suffer no modifications; and local generation is used for self-consumption and the excess, when existent, is injected into the grid.

Fig. 5 – End-users’ preferences for shifting loads (from 0 - maximum flexibility to 1 - no flexibility). The flexibility profile on the left is higher than the one on the right.

Fig. 6 – Controllable load diagrams.
The time step used for simulation purposes was 1 minute in a planning period of 36 hours from 7 a.m. Friday to 7 p.m. Saturday to include a more diverse set of home activities. A short time step is important to account for situations in which there is a sudden rise of (uncontrollable) demand and consequently of power peaks that may endanger the contracted power threshold, thus requiring the EMS to quickly recalculate a more adequate solution (Soares et al., 2015). The evolutionary algorithm was tuned through extensive experimentation. End-users’ preferences concerning the temperature settings of thermostatically controlled loads are presented in Table 5.

Table 5 – End-users’ preferences concerning the temperature settings of thermostatically controlled loads.

<table>
<thead>
<tr>
<th>Loads</th>
<th>Normal temperature variation range</th>
<th>Allowable temperature differences beyond the normal range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fridge</td>
<td>5.5 to 7 ºC</td>
<td>2 ºC, 1 ºC</td>
</tr>
<tr>
<td>Inverter air conditioning</td>
<td>Heating period: 19 to 20 ºC</td>
<td>1 ºC, 1 ºC</td>
</tr>
<tr>
<td>Electric water heater</td>
<td>52 to 55 ºC</td>
<td>5 ºC, 2 ºC</td>
</tr>
</tbody>
</table>
Results

The solutions individually optimising each objective function are summarised in Table 6 and Figure 9. Each solution in the non-dominated front reflects a compromise between the minimisation of the energy bill and the end-users’ dissatisfaction, thus representing different options/profiles of end-users’ preferences.

Results show a small difference of electricity costs between these two solutions in both end-users’ profiles (0.12 €). Although it may be argued that this difference is not significant, it corresponds solely to the energy costs during a period of 36 hours. Reduced flexibility increases the need for a higher contracted power. The optimisation strategy aimed at keeping contracted power as lower as possible (preferably at 3.45 kVA), which was achieved in solutions X, Y and W (Table 6). However, for less flexible end-users, both the reference and solution W required 4.6 kVA. Considering that in Portugal the contracted power cost for 3.45 kVA is 0.1561 €/day while for 4.6 kVA is 0.2030 €/day, additional savings may be achieved by following this strategy.

When compared with more flexible end-users, less flexible ones perceive both a higher dissatisfaction and electricity bill. The higher dissatisfaction is mainly originated by the change of temperature set-points of the thermostatically controlled loads, since a small temperature change is sensed by the less flexible end-users as a deterioration of comfort. The higher electricity bill is due to the limitations imposed to shifting the operation period and change of temperature set-points. In both profiles, the dissatisfaction is mostly originated by the interference with the thermostat temperatures, although end-users’ preferences concerning the admissible range for temperature variations are always satisfied (Figure 10). The model maintains the temperature variations closer to the normal temperature range in solutions minimising the end-users’ dissatisfaction (Y and P) than in solutions minimising the electricity bill (X and W) (Figure 10). In these simulations, higher savings are achieved with demand response actions changing the thermostatically controlled load temperature (solutions X and W) than with load shifting actions. This is mainly due to the current electricity tariff structure combined with end-users’ flexibility. For shifting actions to achieve higher savings, the pricing structure should reflect closer the actual energy generation costs and the end-users should be more flexible and willing readapt their preferences.

Table 6 – Load management solutions. Table notes: The electricity bill only comprises the cost of energy; dissatisfaction is dimensionless.

<table>
<thead>
<tr>
<th>Variables</th>
<th>More flexible end-users</th>
<th>Less flexible end-users</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference (no load management)</td>
<td>Solution that individually minimises the electricity bill</td>
</tr>
<tr>
<td>Electricity bill</td>
<td>3.431 €</td>
<td>3.188 €</td>
</tr>
<tr>
<td>Savings</td>
<td>-</td>
<td>7.0 %</td>
</tr>
<tr>
<td>Dissatisfaction</td>
<td>-</td>
<td>3.556</td>
</tr>
<tr>
<td>Contracted power</td>
<td>3.45 kVA</td>
<td>3.45 kVA</td>
</tr>
<tr>
<td>Difference between solutions minimising the electricity bill and end-users’ dissatisfaction</td>
<td>0.120 €</td>
<td>-</td>
</tr>
</tbody>
</table>
Fig. 9 – Non-dominated front for each end-users’ profiles (more and less flexible).
Fig. 10 – Temperature variation of thermostatically controlled loads for each end-user profile (more flexible – solutions X and Y, less flexible – solutions W and P).

The resulting load diagram of each solution is displayed in Figure 11 and Figure 12. In both profiles, the biggest differences relatively to the reference case occur in the electric vehicle charging process. Thus, while solutions minimising the electricity bill interrupt the charging process to take advantage of the lowest prices, solutions minimising end-users’ dissatisfaction do not interrupt this process. For example, for solution P, 20% of the charge is performed during a higher kWh price. No significant differences exist in the allocation of shiftable loads (other than the electric vehicle) between the reference case and solutions provided by the EMS. This is mainly due to the combination of end-users’ preferences for shifting loads and the pricing structure.
Fig. 11 – Load diagrams for more flexible end-users (reference, solutions X and Y).
Fig. 12 – Load diagrams for less flexible end-users (reference, solutions P and W).
Conclusions

The development of user-friendly enabling technologies is an essential step for the development of more efficient buildings, smart cities and communities. User-friendliness is not only based on feedback features, but also on the functionalities provided, as well as on the capability of capturing preferences. In the presence of dynamic variables (e.g., tariffs, weather conditions) EMS are required to help end-users to optimise their energy management (e.g., demand, storage, local generation and exchanges with the grid) to ensure energy service requirements while minimising the energy bill. Although several load management actions can be technically performed during this process (e.g., shifting, interruption, resetting appliances’ parameters), they are substantially limited by end-users’ characteristics, activities and preferences (e.g., appliances’ ownership, compatibility with routines, willingness to accept load management actions).

This work presented an on-going multidisciplinary approach to design an EMS to optimise energy resources in a residential and small services setting. Future work will further detail end-users’ preferences and profiles, namely by combining this approach with empirical research. Moreover, research will also focus on EMS endowed with learning and adaptive characteristics to promote a higher level of savings and users’ satisfaction.

Acknowledgements

This work has been developed under the Energy for Sustainability Initiative of the University of Coimbra and partially supported by Fundação para a Ciência e a Tecnologia (FCT) under grants SFRH/BD/88127/2012, SFRH/BD/51104/2010, and project grants MITP-TB/CS/0026/2013 and UID/MULTI/00308/2013.

References


ERSE 2015b. Electricity tariffs for small consumers. Energy Services Regulatory Authority


MEE 2014. Statistical data of the system record of microproduction units SRM - Record system of microproduction Ministry of Economy and Employment.

MOBI.E 2010. MOBI.E network. MOBI.E Network.


PORDATA & INE 2015c. Type of households. 26/06/2015 ed.


Session 5: Energy design tools, modelling and data management for the built environment
Natural ventilation in retrofit and new dwellings: a pan-European assessment

Oliver Kinnane 1, William J.N. Turner 2, Derek Sinnott 3, Tom Grey 4

1) Architecture at SPACE, Queens University Belfast, Northern Ireland. Email: o.kinnane@qub.ac.uk
2) Energy Research Group, University College Dublin, Ireland.
3) Department of the Built Environment, Waterford Institute of Technology, Ireland. Email: dsinnott@wit.ie
4) TrinityHaus Research Centre, Trinity College Dublin, Ireland.

Abstract: In an effort to reduce building energy consumption, lessen Greenhouse gas emissions and mitigate climate change, insulation of the European building stock continues unabated. Due focus should be given to the evaluation of new building practice and retrofit priorities as we aim to progress towards a smarter energy Europe. This paper assesses building ventilation when the current trend is to super-insulate the building envelope, in a climate of dramatically increasing temperature. Natural ventilation relies on baseline ventilation provision through background, passive, through-wall venting augmented by purge ventilation as outlined by national regulation in Ireland and the UK (Part F). These means will also be required to provide cooling for naturally ventilated buildings particularly during summer months into coming decades. This paper assesses natural ventilation of dwellings in Ireland and the UK through a modelling study of new and retrofit building typologies. Target and actual ventilation rates are compared with levels specified in regulations around Europe. A designed and built low carbon prototype designed for future adaptation and provided with mechanical means of ventilation is taken for comparison. Based on this analysis the pros and cons of different ventilation strategies into the future are assessed from efficiency, comfort, air quality and domestic anthropological perspectives.

Introduction

Retrofit of the European housing stock ensures efficiency improvement and comfort standard enhancement. In an effort to meet these aims Ireland has focused retrofit of old stock, and regulation of new stock on the reduction of heat loss from buildings by increasing the thermal resistance of the building envelope.

This is not without reason, housing in Ireland is amongst the least energy efficient in Europe [1]. Irish building regulations now specify some of the lowest elemental U-values in Europe, even though the climate is temperate and far from the coldest. However, in doing so Ireland has ignored other key efficiency enabling interventions such as airtightness enhancement. Similarly ventilation standards have received little attention and continue to specify passive uncontrolled ventilation through opes in the building fabric as the primary means of ventilation. This practice allows for the ingress of cold, unconditioned air resulting in heat loss and occupant discomfort, as outlined in this study. A re-evaluation of retrofit priorities is necessary.

Ireland, similar to the UK, is faced with significant housing shortages. Recent efforts to tackle this void have resulted in the development of prefabricated social housing that has received mixed response. Although prefabrication offers many advantages, future housing development requires rigorous design and performance assessment to avoid mistakes of past construction booms. The standard of future houses will likely be a changed typology, focused on maximum insulation and airtightness [2]. In this context the question of ventilation provision increases in significance. Inherent infiltration will
no longer provide for background or make-up ventilation. Designed and controlled ventilation are likely with mechanical ventilation set to become more commonplace. Although low impacting when commissioned well, mechanical ventilation and space conditioning can dominate energy loads of contemporary buildings when poorly configured [3].

This study presents results from a number of on-going projects that are focused on ventilation provision in Irish homes. Selected new and salient results from these studies are presented in this paper. Detailed results, experimental or modelling methodologies are outlined in detail in the referenced studies.

Housing and retrofit

The Irish dwelling stock comprises housing in the majority, 45% of which was built before the introduction of building regulations in 1979. These homes were generally built with little or no thermal insulation, and without any specified ventilation systems. Instead it was assumed that the inherent lack of building airtightness and the adaptive actions of building occupants would suffice to ventilate homes. Much of this building stock is now undergoing thermal retrofit in efforts to reduce its associated load and enhance the thermal conditions within.

To date, in Ireland 300,000 homes have received some form of energy efficiency retrofit upgrade primarily through the government sponsored Better Energy Homes retrofit schemes. The majority of this retrofit intervention is shallow retrofit focused around heating system/boiler improvement, building and attic insulation. One of the many consequences of the installation of insulation during retrofit is the air-tightening of the fabric [4], resulting in an unintended reduction of building envelope leakage of up to 22% in naturally-ventilated buildings [5]. The necessity for provision of ventilation to provide dilution or displacement of indoor pollutants therefore increases.

In Ireland and the UK both natural (natural ventilation with intermittent extract fans, passive stack ventilation) and mechanical (MERV or MHRV) ventilation strategies are proposed for consideration by standards [6] and regulations [7][8]. Shallow retrofit generally provides for ventilation through the addition of background, through-wall vents (Figure 1). A background ventilator is generally an opening, sometimes sleeved, in the external wall, with a deflector cover or louvered cover internally. Ventilation is provided through these vents due to pressure differentials across the dwelling. Naturally-ventilation buildings are commonly prone to under- and over-ventilation due to the variable nature of the natural driving forces; pressure differentials and wind forces.

The ventilation question

Ventilation is required to ensure the provision of constant and abundant air change in homes for the maintenance of good health. Ventilation standards in Europe are set by The European Committee for Standardisation (CEN) although these are not generally harmonised with levels in national regulations [9]. Recent studies have attempted to review and gather ventilation regulation levels and actual levels in European dwellings [10] [9]. As part of an ongoing European study ‘HealthVent’ [11], the arduous task of consolidating ventilation measures was undertaken to enable review of ventilation regulation across European countries [9].

This paper uses the comparison developed in the work of Brelih and Seppanen (2011) to compare ventilation of Irish homes relative to European regulation and practice. A minimum air change rate of 0.5 /h is sometimes referenced in ventilation and health literature as a general benchmark for ensuring adequate ventilation and good health [10],[12],[13],[14]. Although use of this as a minimum threshold is cautioned against [10], it allows for a general benchmark for ventilation level comparison across countries. Many European regulations specify levels below 0.5 [10],[9]. A study by the BRE in the UK [15] showed that 68% of homes had whole house ventilation rates less than 0.5ach [15].

With regard to the energy efficiency and ventilation the European building performance directives reference ventilation only indirectly [10]. The EPBD states that energy “requirements shall take account of general indoor climate conditions in order to avoid possible negative effects such as
inadequate ventilation”. In the pursuit of energy efficiency building envelopes are being tightened. Mechanical means of ventilation are recommended when infiltration levels are low and systems such as Mechanical Heat Recovery Ventilation (MHRV) are increasingly popular particularly in Northern Europe. Mechanical systems come with a significant capital cost and reports of sub-optimal MHRV systems in homes are common. There are also strong cultural arguments in favour of enabling natural ventilation particularly for the home [16]. In Ireland as in much of Europe the aims of residential energy efficiency, and the optimum provision of adequate ventilation, are proving difficult to reconcile [17]. Subsequent sections present case studies of retrofit and new build practice in Ireland and discuss them in the context of ventilation provision, occupant response and efficiency.

**Retrofit: evaluation of common Irish practice**

To assess the impact of retrofit action on Irish housing nine houses of a standard terraced typology are assessed through a monitoring, modelling and post occupancy analysis study. The analysed houses were built subsequent to the introduction of building regulations in Ireland in 1979 and hence contain only limited insulation. In 2013 they underwent a shallow retrofit focused on boiler replacement and improve of the thermal resistance of the building fabric. Significant energy savings were reported, although this varied significantly across houses with many exhibiting

Following thermal retrofit the airtightness of the houses was then assessed using blower doors to conduct pressurisation tests in accordance with ISO standard 9972, as previously described [18]. As a consequence of the thermal retrofit (although not objectively focused on airtightness improvement) the test houses became considerably more airtight as outlined in Table 1.

The external walls were core drilled, sleeved with a 125mm internal PVC pipe and appropriate vent covers were attached where new wall penetrations were required. Any existing vents pre-retrofit were cleared of any debris or blockages.

**Table 1 - Characteristic, geometric and airtightness properties of the nine case study homes used as the basis for this study [5].**

<table>
<thead>
<tr>
<th>Dwelling</th>
<th>Classification</th>
<th>Floor Area Area $m^2$</th>
<th>Orientation</th>
<th>Pre- Upgrade Measured, $Q_{50}$ $m^3/h.m^2$</th>
<th>Post- Upgrade Measured, $Q_{50}$ $m^3/h.m^2$</th>
<th>Improvement [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2, T</td>
<td>80.6</td>
<td>E - W</td>
<td>17.1</td>
<td>13.6</td>
<td>20.2</td>
</tr>
<tr>
<td>B</td>
<td>2, S</td>
<td>89</td>
<td>E - W</td>
<td>12.7</td>
<td>10.2</td>
<td>19.3</td>
</tr>
<tr>
<td>C</td>
<td>2, S</td>
<td>76.9</td>
<td>E - W</td>
<td>19.7</td>
<td>13.8</td>
<td>29.9</td>
</tr>
<tr>
<td>D</td>
<td>2, T</td>
<td>87.7</td>
<td>E - W</td>
<td>9.6</td>
<td>7.7</td>
<td>20.2</td>
</tr>
<tr>
<td>E</td>
<td>2, T</td>
<td>75</td>
<td>N - S</td>
<td>6.5</td>
<td>5.3</td>
<td>18.8</td>
</tr>
<tr>
<td>F</td>
<td>2, S</td>
<td>76</td>
<td>N - S</td>
<td>10.2</td>
<td>8.3</td>
<td>18.1</td>
</tr>
<tr>
<td>G</td>
<td>2, T</td>
<td>79.8</td>
<td>N - S</td>
<td>10.1</td>
<td>6.3</td>
<td>37.9</td>
</tr>
<tr>
<td>H</td>
<td>1, S</td>
<td>46.2</td>
<td>N - S</td>
<td>6.4</td>
<td>5.6</td>
<td>12.7</td>
</tr>
<tr>
<td>J</td>
<td>1, S</td>
<td>49.8</td>
<td>N - S</td>
<td>3.9</td>
<td>4.4</td>
<td>-12.7</td>
</tr>
</tbody>
</table>

Dwellings selected for this study

1 or 2 storeys high

T = Terrace, S = Semi-detached

1,2,3 = N - S North - South

4 = E - W East - West

Through-wall ventilation: common Irish practice

Following thermal retrofit, further retrofit measures were conducted to ensure that each dwelling was compliant with Building Regulations 2009, Technical Guidance Document F – Ventilation [19]. The requirements varied by dwelling, but retrofit measures included fitting the following:

- constantly open louvered passive vents in living areas;
- hit and miss vents in all bedrooms;
- mechanical hood extract fans and constant open passive vents in the kitchen;
- mechanical wall vents wired into the light switch in bathrooms.

Occupant feedback, one heating season after the installation, was almost universally negative about the means of ventilation provision. Occupants complained about the noise of the mechanical vents in the bathrooms which in most cases were turned off. Instead occupants opted to purge ventilate the room after use. They also complained about draught discomfort particularly due to cold air dumping from high vents onto seating and beds. Excessive street noise coming through the new background ventilators was also a common annoyance.

A computational fluid dynamic study was undertaken to evaluate the impact of passive through-wall vents on the thermal environments of rooms within modelled case study homes. These models were validated against experimentally monitored airflow and temperature data in an assessment of airflow through-wall vents in a terraced inner city Dublin housing [20]. An example assessment of outdoor air ingress through a wall vent is shown in Figure 1. The air is seen to drop from the high wall vent and impact internal living space commonly occupied by seated, sedentary occupants.

![Figure 1 - CFD assessment of cold air ingress into the living room of housing model shown (inset). Assessment is made of a south-westerly facing façade during windy (12m/s wind speed from south-west), winter conditions (13 °C external temp.). Indoor temperature set-point (20°C).](image_url)

Table 1 lists two housing types of similar cavity wall construction, one 75-90 m² and the other in the 45-50 m². Using CONTAM, airflow network models are developed of these houses with floor areas of 50 m² and 90 m². These models allow for assessment of passive ventilation levels attained using through-wall vents installed during housing retrofit. To meet the requirements of building regulation TGD Part F the 50 m² house requires an area of 35,000 mm² and the 90 m² house requires an area of 40,000 mm² of wall vent area.

For comparison of the variability and wide ranging passive ventilation rates provided using through-wall vents, the target ventilation rate (At) is modelled as the mechanical ventilation rate for dwellings...
documented in Part F (Figure 2 - Figure 3). S1 and S2 document annual mean effective ventilation rates (and not the simple average ACH) pre and post installation of through-wall vents.

**Ventilation levels: comparison with European ventilation levels and standards**

The resultant air changes due to ventilation retrofit practice are here presented in the context of European ventilation levels. The European study ‘HealthVent’ has gathered ventilation rates (primarily those documented in national building regulations) from across Europe as documented by Brelih and Seppanen (2011). In both pre and post through-wall vent installation the small 50m² house exhibits ventilation levels below target ventilation rates, as defined by mechanical ventilation requirements. Considering this the house is shown to be under ventilated. Although only just below target levels under ventilation could resulting in likely substandard air quality and possible complications arising from inappropriate air exchange rates.

**Figure 2 - The analysed 50 m² house exhibits under ventilation even after installation of passive through-wall vents.**

The addition of passive through wall vents to a 90 m² house with relatively good airtightness (0.22 annual mean effective ventilation) improves its ventilation to levels above the target rate as documented in Figure 3.

**Figure 3 - Installation of through-wall vents increases the ventilation levels from below target levels in the 90 m² house.**
In contrast an example of the 90 m$^2$ house with high infiltration rates exhibits annual mean effective ventilation rates at the far end of the European scale (Figure 4). Air exchange rates before installation of through-wall vents are already well above target levels.

**Figure 4** - house with poor airtightness exhibits high levels of air change pre vent installation. Addition of a regulatory necessary vent increases the air change further.

Countries such as Germany and the Netherlands, that place good emphasis on dwelling ventilation regulate for similarly high ventilation rates. However in the uncontrolled nature of provision as occurs during passive through-wall ventilation this additional ventilation can induce strong cooling effects at unwanted times and high compensatory heating energy loads.

**New housing typology: a case study**

These authors presented details of an energy efficiency case study housing typology in the context of its supply chain evaluation, for COST TU1104. This housing case study (LCAH) is here revisited to evaluate an alternative ventilation method to the current common passive ventilation.

**Figure 5** - The Low Carbon Adaptable Home (LCAH) case study building (left) original concept, (right) built core house with single pod addition.

The LCAH is an airtight, highly insulated house prototype developed as a proof of technology for a light-gauge steel prefabricated manufacturer. It uses a mechanical heat recovery ventilation (MHRV) system with an air-to-air heat pump, but without cooling capability beyond night-time cooling through forced cool outside air supply. In the drive toward energy efficiency MHRV systems are gaining in popularity although their high capital cost is one reason why they still represent a niche product. However, due to their association with low energy housing, and particularly the PassivHaus typology, they constitute the alternative and other primary ventilation method presented in TGD Part F.
The LCAH is primarily electricity consuming and an extensive monitoring system [21] records load consumption in detail and based on behavioural and functional loads, as well as thermal and air quality. The space conditioning system accounts for 52% (5477 kWh) of the total electricity consumption of the house. The system exhibits a higher than expected energy consumption particularly during the heating season. High loads are particularly obvious in the early periods of occupancy when occupants struggled to understand the system and controls.

**Natural and mechanical ventilation: a climate change assessment**

To assess the performance of the LCAH in future climates it was simulated using climate projection data developed by the University of Exeter in the Prometheus project. When assessed in a purely mechanically ventilated mode, with no solar shading or other adaptions, significant overheating hours were observed from 2050 onwards, reaching 15% above 28°C, and 27% above 25°C, of all hours by 2050. When instead assessed in a mixed mode scenario with predominant summer time natural ventilation, less overheating is observed (8% (above 28°C) and 27% (above 25°C) of all hours). By end of century overheating becomes commonplace. It is likely, particularly for the elderly and vulnerable, that auxiliary means of cooling would be required to maintain health and well being. Solar shading was observed as the most consequential of adaptions available to reduce the overheating impacts of climate change.

**Discussion**

Retrofit of Irish housing has improved energy efficiency through a reduction of heat loss, and an unintended improvement in building airtightness. Shallow retrofit measures implemented on a set of houses of a common typology are shown to improve efficiency and comfort levels, however consumption varies remarkably across homes, in part due to a considerable variation in air tightness levels.

High infiltration levels, or a general lack of airtightness in Irish dwellings, have a defining impact on the air exchange rates of dwellings and requires greater consideration in new and retrofit in Ireland. Current means of ventilation provision in new and retrofit scenarios, commonly provided by through-wall vents, is unreliable and results in widely varying air change. Irish air change levels are not outside the range of European ventilation levels. Approximately a third of all European countries reviewed have requirements for the ventilation of dwellings below 0.5 /h, a commonly used ventilation benchmark. Controlled ventilation is however more commonplace in many of these European countries, particularly in countries that specify high air change levels. In many cases these are aligned with heat recovery enabling added efficiencies and energy savings.

A designed and built energy efficient prototype home is shown to exhibit higher energy consumption than anticipated by simulation studies. High levels of thermal comfort and occupant living satisfaction are reported but occupants report frustration with the unfamiliar means of heating and ventilation. When analysed in climate change scenarios significant overheating hours are observed. The air conditioning system including MHRV and air-to-air heat pump are unable to reduce overheating hours in severe scenarios. A mixed mode operation, allowing for passive/purge ventilation override is most promising, however for elderly or vulnerable populations auxiliary means of cooling will likely be required before century end.

Interestingly the occupant response to two very different strategies of home ventilation (passive through wall & MHRV) are characterised by frustration and uncertainty with the aims of the ventilation strategy implemented. A general lack of understanding on the part of the occupant and appreciation for the necessity and value of good ventilation are reported during these assessments.

Added focus is required in Irish building regulations on ventilation to ensure reliable and consistent air quality and air change. Key to this is guidance on means of ventilation provision beyond basic through-wall ventilation, or costly whole house systems. A plethora of alternatives are now available
that can offer solutions that are not particularly invasive, or costly but provide for constant good air quality. Regulations should reflect and not restrict these options as alternatives.

References


Performance-based clustering for building stock management at regional level

Philipp Geyer 1, Arno Schlueter 2

1) KU Leuven, Kasteelpark Arenberg 1 - box 2431, 3001 Leuven, Belgium.
2) ETH Zürich, Switzerland
Corresponding author: Philipp Geyer, p.geyer@kuleuven.be

Abstract: To facilitate the energy transition, the retrofit of building stocks is a crucial task. A strategy is required to maximize the effect of retrofit to reduce GHG emissions in the given limits of the available investment means. The paper shows that type-age classifications of buildings are not an appropriate grouping for strategy development and proposes an algorithmic clustering as grouping method based on the effect of energy efficiency measures (EEM). This novel clustering method delivers groups of buildings that similarly respond to retrofit measures and thus provide a good basis to develop efficient large-scale retrofit strategies. Besides illustrating the method and its benefits, the paper draws conclusions on the transfer of the method to a regional scale. These conclusions address aspects of the larger heterogeneity of the building stock as well as data availability, scaling and supply structures as well as the utilization of the results for policy making.

Introduction

The objective of energy efficiency and emission reduction in urban structures requires the management of and strategy development for building stocks. A central requirement is the determination of the potential of energy efficiency measures (EEM), the related reduction of emissions and the potential for decentralized energy production considering the usual limitations of investment means. As it is, especially at regional scale, not possible to assess each individual building for EEM, building stock models and strategy development tools usually base on type-age classifications of buildings. The groups derived on this basis not necessarily react uniformly on EEM, which is shown at the end of the paper, and therefore do provide not a good basis for strategy development and policy making.

Therefore, the paper presents an approach using algorithmic clustering to derive groups that react similar on EEM. The background for this approach is that due to the digital revolution and smart technologies much more data are available that allow a far better prediction of the effect of EEM. However, the challenge is still to derive strategies to make these data for retrofitting and respective policies usable for decision making. The aim is a management of the building stock to renounce from fossil fuels and to drastically reduce the CO₂ emissions. Therefore, the purpose of applying algorithmic clustering is the derivation of strategies for the building stock, as the local government wants to approach the owners to propose measures and to establish a support program for retrofitting etc. For this purpose, it is key to identify groups of buildings that require the same measures to realize potential energy savings and to be able to find the groups automatically for that an investment has the best effect in emission reduction.

Dealing with large urban buildings stocks and decision making for investments, the pure number of buildings in urban structures provides an obstacle in the development of such retrofit strategies. This problem aggravates at a regional level because the number of buildings increases and even the
conditions (energy tariffs, accessibility of energy carriers etc.) may vary. It is purely impossible to examine such numbers of buildings one after the other and proposing retrofit strategies. Also the type age classification is not a good approach for assigning retrofit strategies to building groups, which will be shown at the end of the examination. This situation calls for an advanced computer-aided analysis method.

To address this problem, the paper proposes in Section 2 to use detailed building data for an approach of clustering the building stock by means of hierarchical clustering. This clustering is based on effectiveness of measures for emission reduction. The method supports the management of the building stock for the planning of large scale retrofit measures.

From this approach groups of buildings result that react similar to EEM. These groups allow for an easy selection of strategies for reducing emissions. Planners and decision makers can select appropriate measures and measure combinations. The reaction on the EEM determined by the method helps in this selection process. Furthermore, scheduling the measures within the development horizon by considering an available investment budget and starting at most effective measures leads to an effective retrofit strategy over time.

So far this clustering approach has been developed for the district and urban scale. Section 2 is therefore a recapture of the existing and previously published method (Geyer et al. 2014). In Section 3 we extrapolate the potential of the method to address the regional scale, which poses additional demands on the management of buildings stock due to the increased number of buildings and more heterogeneous boundary conditions.

**Background**

To simulate and propose retrofit measures for building stocks, the type-age classification has been introduced. Type-age classification assumes a correlation between the building age and energy consumption as a basis for retrofit planning. A typical instance of the type-age classification for Germany has been developed by the Institut für Wohnen und Umwelt (IWU) and recently extended to Europe (IWU, 2014). An alternative approach for identifying energy-related parameters within large building stocks is clustering: Santamouris et al. (2007) apply clustering to a database of 320 schools in Greece and build groups based on the energy consumption with climatic normalization. Hernandez et al. (2008) do a similar study. Phil Jones et al. (2001) cluster a building stock by building properties, such as heated ground floor area, facade, window to wall ratio. Gaitani et al. (2010) identify typical building properties / parameters for the clusters of the schools in Greece. Yamaguchi et al. (2007) identify district types and provide typical energy performance by simulating buildings in a representative district. Swan and Ugursal (2009) provide an overview of modelling techniques for the energy consumption of residential building stock. However, none of the previous research project applied clustering based on effectiveness of multiple measures to develop retrofitting strategies for a building stock, which is needed for strategy building and decision making.

**Zernez Case Study**

The proposed methods are demonstrated in Section 2 using the case study of Zernez, an applied research project for the transformation of a Swiss alpine village towards zero emissions in building operation. Aim of the research project Zernez Ener gia 2020 is to develop an action plan for a transformation strategy for the building stock and energy systems to become emission free within the near future. A combination of retrofitting existing building stock, transformation of energy systems for heat, electricity, a model for urban development strategies and sustainable growth of the community including an integrative planning process should enable the municipality to develop and apply measures and policies.
One key part of the project was the research and development on environmentally and economically effective retrofit strategies for the building stock. Since the financial means of building owners and the support by the municipality are limited, it is crucial to identify which measures are most effective for building retrofit. The setting of the project creates a possibility for formulating a bottom-up approach based on real building data. Together with the application patterns, the municipality surveyed and compiled a list of more than 50 parameters for each building including the last retrofit, the condition of the building substance, area, installed heating and domestic hot water system, consumption data if available, images and plans for easy recognition and context. A building database was established to quickly access all building parameters for further analysis and calculation. Each building was identified with an identification number, 3D-modelled and inserted into a GIS model for analysing photovoltaic potential (e.g. on roofs) and associated with a spreadsheet. These data serve as basis for the building-detailed analysis and performance-based clustering described in Section 2.

The analysis of the buildings in this database revealed that there are high variations in the energy consumption by the year of construction. Not the oldest buildings have the highest energy consumption but that one from the 20th century on, as shown in Figure 1 top left exemplarily for one building type, the residential buildings of Zernez. The reduction of the energy consumption by one typical retrofit action, which is the insulation of the façade and the replacement of the heating system, shows a very varying reaction (Column 4 of Figure 1). For this reason, a better adapted approach than the type-age classifications for grouping and strategy development was necessary.

Fig. 1 - Analysis of the building type “residential” in the building stock of Zernez by construction year.
The method of performance-based clustering for building stock management

The aim of the clustering is to develop groups of buildings that respond similar to the same EEM concerning the reduction of CO₂ emissions. The basis for the clustering is the response of the individual buildings to selected EEMs and measure sets. The clustering method identifies similarities in the responses and groups the buildings to clusters with a specific characteristic. This characteristic directly bases on the impact that the measures have instead of indirect indicators such as building type and age. Figure 2 gives an overview of the data preparation, the pre-processing, the clustering and the post-processing to develop retrofitting strategies. The following subsections provide an outline of the process which is described in detail by Geyer et al. (2014, 2016).

Effect of retrofit measure effects

Four different retrofit measures for reducing CO₂ emissions in operation were defined. These were selected according to best practice examples of successful retrofits of the buildings in the village and include measures to reduce energy demand as well as measures to harness locally produced renewable energy sources. The selected measures included: (1) insulation of the envelope, (2) exchange of the heating systems (exemplarily by a heat pump), (3) decentralized electricity production (by a photovoltaic system) and (4) decentralized heat production (by a solar thermal system). Figure 3 provides an overview of the measures, their combinations and constraining rules.

---

![Flow chart showing the method of determining clusters and strategies from the given building stock database (Geyer et al. 2014).](image-url)
The basis for the clustering is an automated analysis of the effects of the measures and the selected combinations for each building. This analysis uses the detailed database of the current constitution of the building and their energy consumption described in Section 1.2. Each measure was executed for each building in the database using the descriptive parameters of geometry, state of construction and heating system and further constraints, such as historic protection etc. Simplified energy calculations depending on the real energy consumption serve to determine the reduction of the total CO\textsubscript{2} emissions per building by each measure, which forms an effect matrix.

The simplified energy calculations bases on the geometric information from the database, such as gross floor area, roof form and area, orientation etc., information on the construction, such wall construction, windows area and types etc., and on the energy consumption for heating and the electricity consumption. First, the share used for heating, for domestic hot water and for electricity consumption is constructed; for a part of cases, in which data are missing, assumptions on typical distribution were used. The construction of this share of consumption is required to assess the impact of the measures on the total building emission. As next step, estimation for the missing parameters of the building geometry takes place resulting in the following set of parameters: gross floor area, the areas of envelope, façade, windows, wall, roof and foundation as well as roof area available for photovoltaics and solar thermal systems. Together with the information on the construction and on CO\textsubscript{2} conversion factors describing the energy supply, the calculation of the reduction of emissions by applying the measures is possible. This calculation considers several constraints, e.g., that external insulation is not applicable to a historic façade or that a heat pump system with low temperature radiators should not be combined with a badly-insulated façade; this is the implementation of the constraining rules shown in Figure 3.

**Fig. 3 - Overview of the measures with constraining rules and their combinations for emission reduction (Geyer et al. 2014).**

**Clustering**

The next step is the clustering of buildings. The basis for the clustering is the response of each building to each measure of the previous step, which is comprised in the effect matrix. The interpretation of this matrix as multidimensional feature space. In this virtual feature space, buildings that react similar to EEM are located close to each other. This space provides the basis to identify groups of buildings.
by means of distance-based clustering methods. The both main types of clustering, which are hierarchical and partitioning clustering, perform well for this identification (Geyer et al. 2016).

Figure 4and 5 show exemplary results for the case of Zernez. These results are based on the percentage of emission reduction per building (X and Y axis of all diagrams). Alternatively, other scales are possible and appropriate depending on the objective of the strategy, which we already have shown (Geyer et al. 2016). In the buildings stock of Zernez, four clusters are identified.

In post-processing, representative buildings were selected for each of the four clusters to select a combination of measures that is most appropriate. A post-processing algorithm searches the building closest to the centroid but excludes buildings for that the data source is unsure because of missing entries and assumptions or that are marked as special buildings, such as the school or the sports hall. Figure 6 shows such a representative building for Cluster 4. The selection of such buildings supports the development and validation of developed strategies by planning a specific retrofit action.
Fig. 6 - Representative building in the Zernez building stock for Cluster 4.

Figure 5 shows one scatterplot in detail that allows the exemplary interpretation of the identified clusters. The diagram shows the reaction of the buildings (each symbol is one building from the stock) on the measure photovoltaics (G1, Y axis) and the measure combination insulation of the envelope and solar thermal heat supply (E1+G2). So it shows an electricity measure versus a heat consumption measure. This illustrates the four identified clusters, the measures and their combinations:

Cluster 1: These buildings react more on electricity saving measures (G1) and on heat demand reduction (E1+G2). Therefore, photovoltaics are a good option for them whereas their heat demand is low so that respective measures, especially insulation, have a limited effect.

Cluster 2: This cluster comprises buildings with a high heat demand and/or a badly insulated envelope. Measures on reducing the heat demand have a high effect on reducing CO₂ emissions. Also photovoltaics work well.

Cluster 3: The building in this cluster moderately react on the electricity reduction measures. The reason is that they have only little roof area for photovoltaics due to their compact body. However, due to the high overall CO₂ reduction potential compared to the prices, photovoltaics are applied as well as heating energy reduction measures.

Cluster 4: This cluster includes buildings that have high reduction of CO₂ emissions by photovoltaics going above 100%, which means they are plus energy buildings. Often these are secondary buildings such as garages and storage buildings having low electricity consumption and no heat consumption allowing the production of energy for other buildings in the village.

From these reactions on the measures and by consideration of general cost information, recommended measures per cluster are developed. The following table shows these recommended measure combinations:
Table 1: Measure combinations developed as strategies for the clusters.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Measure Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>S1 + G1 + G2</td>
</tr>
<tr>
<td>C2</td>
<td>E1 + S1 + G1 + G2</td>
</tr>
<tr>
<td>C3</td>
<td>E1 + S1 + G1 + G2</td>
</tr>
<tr>
<td>C4</td>
<td>G1</td>
</tr>
</tbody>
</table>

This exemplary interpretation and the recommended measures show how the clusters can be serve to develop strategies for retrofitting and for policy making for the village’s future energy strategy.

Cluster analysis

Finally, the data analysis of the building stock following the classification shows that the clusters provide a far better classification than the building age with fewer and therefore easier to manage categories. To illustrate this advantage, the effect of one exemplary measure combination, which is E1 + S21, i.e. the insulation of the façade and the exchange of the heating system is compared. On the right of Figure 1, which analyses the residential buildings in the building stock of Zernez by construction year, the reaction on this exemplary measure combination is shown in the fourth column. These reactions exhibit high variation, indicated by the black range symbols, for all larger building groups, i.e. those built in the 1870 and between 1960 and 1990. In contrast, the same analysis for the clusters in Figure 7, forth column exhibits nearly no variation. This means that measures based on cluster analysis are very precisely plannable without a high risk of being inadequate.

Fig. 7 - The data analysis of building stock by cluster shows the far better similarity of the buildings than an analysis by construction year.

Transformation strategy development

Taking a given budget into account, as for the case study given by the available investment means of the community, transformation strategies for a whole region can be developed. For this purpose, investment costs for measures are assessed and the cost effectiveness, which is the amount of CO₂ emission reduced per year per invested Swiss Franc. The cost effectiveness of the measures determines the required investments per cluster. Considering the available budget per year, the duration of the retrofitting of a cluster is known.

From this information, a transformation path is derived such as outlined in Figure 8. The reduction potentials in percent shown in Figures 4 and 5 together with the absolute emission volumes and the required investments for the developed measure combinations (Table 1) form the basis for the transformation path. This path follows the assumption that the retrofit starts with the clusters and measures of the highest cost effectiveness. This means to start from the lowest hanging fruits to quickly achieve reduction of emissions. A further study under publication will illustrate this with real data (Geyer et al. 2016).
Residential energy consumption accounts for about a third of EU’s total energy consumption (European Commission 2015). The majority of the heating systems still uses fossil fuels (European Commission 2015a). This causes a high volume of anthropogenic GHG emission. Thus, an important goal is the reduction of these emissions by retrofitting the building stock. In this context, the building stock management plays a major role. Building retrofit requires high investments and it is required to invest limited available means with the best effect.

Performance-based clustering allows to identify groups of buildings that have high priority for retrofitting in order to quickly reduce the emissions with the available budget. Especially at regional level with varying external conditions, the approach allows the identification of well-fitting groups and strategies in heterogeneous building stocks. Such varying conditions are caused by large-scale supply structures, such as power plants and district heating systems, local energy prices, changing climate conditions, renewable sources (hydropower, geothermal etc.), economic state of a region etc. The clustering approach dynamically adapts to the situation and thus far better adapts to given conditions than the rigid type-age classification and thus far better meets the individual characteristic especially at a regional level.

These resulting clusters that are adapted to the specific conditions are a very valuable source for regional energy policy development and for the steering of investments. Interpretation allows the derivation of well-fitting retrofitting and investment policies. In the forthcoming study of Zernez (Geyer et al. 2016) it could be shown that with the same investments using the clustering-derived strategy 80% of the emissions of the buildings can be avoided compared to 20% in case of business-as-usual with the same budget.

Up to now, the method has not been applied to very large building stocks, which is planned in future research. However, the following subsections provides an assessment of the application of the method in such a situation.

**Data availability**

Compared to the type-age classification, the clustering approach requires more data. Some of these data, such as energy consumption, are connected to economic interests and privacy issues. However,
in the context of the smart cities and smart regions paradigm, there is a strong force making these data available. The expectation is that for regional strategy development in near future a far better data basis available. Furthermore, the clustering approach is also applicable on the basis of limited data availability. This would decrease its representation of consumption but still adapt to the specific characteristics of the building stock and support far better policy development and strategic investment than a conventional approach.

**Precision in terms of energy consumption**

Compared to the type-age approach, which usually proposes EEM only based on one example building per group and the test of EEM for this specific building by building-level simulation, a far higher matching to the overall group characteristic can be expected by clustering. Although the applied simplified energy calculations have not the precision of the building-level energy simulations, the overall fitting and prediction per group is far better by taking into account all buildings.

Furthermore, in case of Zernez, monitored consumption data from a survey were available and the clustering is based on these data by calculating relative effects of EEM. Such a situation will become increasingly available in future by smart metering etc. The use of such data far better fits retrofitting to the real situation of energy consumption than to assume theoretical data in simulations.

**Scaling of the method**

Assuming an automated process of data acquisition and assessment of measure effects in context of smart regions, the number of buildings, which are the instances for clustering procedure, increases significantly. Therefore, a well-scaling behaviour for large number of instances in clustering is therefore of importance. Typically hierarchical clustering has a computational complexity of \(O(N^2)\) (Xu and Wunsch 2005), which means that the computation time is proportional to the squared number of buildings. For the Zernez case with 300 buildings, the computation time of clustering did not play a role (it was below a second on a usual PC). However, the quadratic behaviour leads to a significant increase going to 30,000 buildings, which is a usual amount for a region. However, other clustering algorithm behave much better. For instance, the partitioning clustering algorithm k-means performs better with a complexity of \(O(NKd)\) with \(N\) objects, \(K\) clusters and \(d\) dimensions (Xu and Wunsch 2005), which means a linear increase of calculation time with the number of buildings. A test on the Zernez data revealed that the results of both clustering methods do not much deviate (Geyer et al. 2016).

**Considering decentralized supply structures**

A further aspect of building stock management as a bottom-up strategy for the energy transition needs to go beyond the building level. The energy transition cannot be solved at building level only. Also in this context, clustering can help to identify buildings for measures. However, in this context the spatial aspect has high importance because supply structures and networks strongly rely on location of supply and consumers. In a further forthcoming study, we present a method to identify thermal microgrids in a building stock based on clustering and fuzzy logic (Schlueter et al. 2016). These data mining methods select buildings that are appropriate to join a small local heat network and spatially group them into microgrids. A further potential of similar applications is expected.

**Policy making**

Besides the direct approach of building owners to propose retrofit actions, especially at regional level, it is of interest to develop retrofit policies. The proposed clustering method very well supports the activities of policy makers. The groups of buildings derived by clustering may directly serve for the setup of subsidy programs. The method not only delivers effective EEM per group but also, by looking at similarities in building parameters of a group, allows to derive rules for such subsidy programs. For example, the use of a heat pump in Cluster 4 in the Zernez case has a high effect. An examination of
the group parameters shows that the predominating electric resistance heating systems are the reason for this behaviour. From this information, a subsidy program for the exchange of such electric heating systems by heat pumps can be derived.

Conclusions

Data mining methods, such as clustering, have a high potential to support the planning and strategic development of the retrofit of building stocks. They allow to focus investments on building groups and strategies that have a high effect for a given investment budget. Especially moving to regional level in the context of smart cities and smart regions requires intelligent computer support to gain strategic information from large data bases. The presented approach showed significant better adaption of proposed measures and strategies than conventional classification approaches as the type-age classification.

Upcoming smart cities and regions will lead to large volumes of data available. This will lead to much higher importance of data mining and further intelligent computation. Whereas the type-age approach relies on many unsure assumptions in terms of similarity, typical utilization, construction and performance of the buildings in one group, data mining provides the means to exploit the available data, such as shown for the clustering approach for strategic retrofit development. In the context of smart built structures, we recommend such methods instead of traditional type-age approaches. We expect that such methods will gain increasingly in importance for planning and strategic development of an energy efficient and sustainable built environment.

Acknowledgements

We thank our collaborators of the research project ‘Zernez Energia 2020’ for the exchange of data related to cost, energy conversion and building energy calculations. This research was partly funded by the Swiss Commission for Technology and Innovation (CTI).

References


The role of analytical tools in supporting sustainable local and regional energy and climate policies

Monica Salvia, Senatro Di Leo, Filomena Pietrapertosa and Carmelina Cosmi

Abstract: Energy and climate decision-making is a complex issue that involves interconnected systems (energy supply, transport, households, etc.) requiring a comprehensive modeling approach. In the latest years regional and local authorities have assumed a leading role in facing climate challenges and contributing to the Europe 2020 objectives, although their little knowledge of local energy systems still represents the main barrier. Municipal energy plans and the related energy balances are often compulsory only for larger cities (as in the case of the Italian Law n. 10/91) and data availability is a common problem due to the absence of adequate statistics or databases at local and regional scale. On the other hand, initiatives such as the Covenant of Mayors have boosted the development of sustainable energy action plans (SEAPs) that are based on the compilation of energy and CO\textsubscript{2} inventories, covering key target sectors (buildings and transport, usage of renewable energies and CHP).

Despite the large number of decision support tools made available by the scientific community (e.g. MESSAGE, MARKAL/TIMES, LEAP), municipalities and regional authorities rarely use analytical tools to support the policy-making process. These tools have different features and fields of application requiring different levels of expertise. This study aims at providing energy planners and Local and Regional Authorities all around Europe with an overview of the most effective analytical tools to support energy and climate decision making. The broad scope is to foster public authorities to adopt analytical tools for strategic planning with a long-term vision in order to improve steadily the energy system performances in compliance with the energy and climate targets at European and national scale.

Keywords: Energy and Climate planning, Decision Support Tools, Local and Regional Authorities, Energy System Analysis.

Introduction

The 2020 climate and energy package and the related “20-20-20” targets set for 2020 represent an important first step towards building a low-carbon economy in Europe. In addition to that, the ten-year strategy Europe 2020, launched in 2010, aims at creating the conditions for a smart, sustainable and inclusive growth and covers employment; research and development; climate/energy; education; social inclusion and poverty reduction (European Commission, 2015).

However, Europe looks beyond 2020 defining tighter environmental policy targets and objectives by 2030 and 2050. A new 2030 Framework for climate and energy was agreed by the EU countries (COM 15 final, 2014), which includes EU-wide targets and policy objectives for the period between 2020 and 2030. These targets aim to help the EU to meet its long-term goal of reducing greenhouse gas emissions by 80-95% when compared to 1990 levels by 2050 (Energy Roadmap 2050 (COM 0885 final, 2011)).

The EU2020 objectives have been translated into national objectives by the national governments recognizing that the contribution of local and regional authorities to the realization of the EU2020
agenda is very important, as pointed out by the Committee of the Regions (European Union, 2011). Local and regional authorities play a crucial role to achieve the European and national energy and climate targets and to support the transition towards more sustainable energy systems as they initiate and implement policies and are responsible for a large part of the economic structures in their cities and regions.

The transition towards a low-carbon society requires multifaceted interventions aimed to promote energy savings, renewable energy sources and an efficient use of fossil fuels. These interventions affect different sectors and local/regional competences, from energy supply (e.g. heat and power generation) to the energy demand sectors (e.g. residential and commercial buildings, urban and regional transport) requiring considerable investments to update infrastructures.

Strategic energy and climate planning is carried out mainly at the regional level while the implementation of the multilevel goals and policies takes place on a local level through planning, local cooperation, partnerships (Kjaer, 2012). In this framework, it should be pointed out that Sustainable Energy Action Plans (SEAPs) developed by municipalities signatories of the Covenant of Mayors (CoM, 2015) bypass the national level and set climate goals at the local level where the action plan is implemented.

This paper starts introducing the main concepts of local energy and climate planning. In the following sections the paper analyses the main decision support tools and energy models currently available, focusing on those actually used by local and regional authorities. A critical review of the findings and main outcomes of this research is then provided in the conclusive section.

**Local and regional energy and climate planning**

Local and regional authorities play an important role in the achievement of the EU and national energy and climate targets due to the proximity to citizens and because they “act as: energy consumers and service providers, planners, developers and regulators, advisors, motivators and role models, energy producers and suppliers, buyers” (Energy Cities, 2013). Several initiatives have been promoted to provide networks, information sharing and knowledge transfer, such as the ManagEnergy Programme (2015) and the Covenant of Mayors with the participation of a large number of EU cities and communities.

Developing an energy and climate plan is an effective and important first step to reduce greenhouse gas emissions through improved energy efficiency and increased use of renewable energy (Enova, 2008).

According to the Advanced Local Energy Planning (ALEP) methodology (Jank et al, 2005), local energy and climate planning generally starts with a preparatory phase in which the main objectives and boundaries of the planning process are set up as well the organizational aspects and the key roles (Figure 1). In the next step, the reference energy system (from energy supply to end-use demands) is in-depth characterized in terms of infrastructures, availability of present and future technologies, energy needs by end-use, and environmental impacts. Then the modelling environment is set up and calibrated on the local case study. A scenario analysis is carried out to analyze alternative pathways of development of the energy system in comparison with a reference scenario (BaU, Business as Usual) in order to devise robust policy strategies. The latest steps of a planning process deals with the implementation of the devised strategies, identifying policy measures and incentives that allow translating the model results into concrete actions, and monitoring the achievement of the planning objectives with possible feedback on the planning strategies, following an iterative approach.
Similarly, the EASY (Energy Actions and Systems for Mediterranean Local Communities) methodology proposes a reference model to define Local Sustainable Energy Strategies with a special focus on Mediterranean cities (Easy IEE project, 2009). They propose four macro stages, tightly interwoven and complementary, all developed via a cross participation process. First, an assessment stage focused on analyzing the entire Energy System in the area and all the related issues, concerns, and weaknesses (Figure 2). Second, the planning stage in which the Local Action Plan for Sustainable Energy is developed pointing out strategies, objectives, and priority actions for the local energy system. Third, an implementation stage dealing with two main steps: (i) the development of single projects that put in action the contents of the local action plan, and (ii) the construction of a beginning scenario (minimal measures, small investments, short timings, small number of local participants) to then arrive, through a series of scenarios, at a final one that is more complex, integrates various projects, has long development times, needs more financing, and requires many local participants. Finally, an evaluation and reporting stage based on the use of a sustainability indicator system in order to monitor the progressive application of the local action plan and evaluate the results obtained so that local administrators can decide whether to adopt corrective actions, review objectives or restart a new energy planning cycle.

Fig. 1 - Overview of the main planning phases, according to the ALEP methodology.
Overview of decision support tools for energy system analysis

The scientific community has developed a large number of decision support tools, properly designed to help decision makers in defining robust climate change mitigation strategies and choosing the best pathway towards a low carbon future. By searching in scientific databases, a long list of available tools can be obtained. How regional/local administrators can disentangle themselves in this wide landscape of energy models and select the tools more appropriate for their scopes?

In order to steer public administrators to adopt decision support tools for planning sustainable energy and climate strategies, a classification of selected tools is needed. Table 1 provides a non-exhaustive overview of the most widespread tools sorted on the base of scale and field of application, mathematical approach, as well as level of expertise required and models’ availability (Allegrini et al, 2015; Connolly et al, 2010; Keirstead & Jennings, 2012).
Table 1. Overview of the main decision support tools for energy and climate planning.

<table>
<thead>
<tr>
<th>MODEL NAME</th>
<th>GEOGRAPHICAL AREA</th>
<th>ANALYZED SECTORS</th>
<th>ROUTINE</th>
<th>TARGET USERS</th>
<th>AVAILABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>2050 Calculator</td>
<td>National regional</td>
<td>Entire energy system</td>
<td>Simulation</td>
<td>Policy-makers, Citizens, Students</td>
<td>Free download from: <a href="http://www.decc.gov.uk/2050">www.decc.gov.uk/2050</a></td>
</tr>
<tr>
<td>Balmoriel</td>
<td>National</td>
<td>Electricity, combined heat and power</td>
<td>Optimization</td>
<td>Experienced energy system modellers</td>
<td>Free download from: <a href="http://balmorel.com/">http://balmorel.com/</a></td>
</tr>
<tr>
<td>Calliope</td>
<td>National regional</td>
<td>Entire energy system with a focus on the electricity system</td>
<td>Optimization</td>
<td>Experienced energy system modellers</td>
<td>Free download from: <a href="http://www.calliope.com/">http://www.calliope.com/</a></td>
</tr>
<tr>
<td>DESSTINEE</td>
<td>European energy system</td>
<td>Entire energy system with a focus on the electricity system</td>
<td>Simulation</td>
<td>Experienced energy system modellers</td>
<td>Free download from: <a href="http://tinyurl.com/desstinee">http://tinyurl.com/desstinee</a></td>
</tr>
<tr>
<td>DIETER</td>
<td>National</td>
<td>Electricity system</td>
<td>Optimization</td>
<td>Experienced energy system modellers</td>
<td>Free download from: <a href="http://www.diw.de/de/diw_01.c.508843.de/forschung_beratung/projekte/projekt_hometeys/dieter/dieter.html">www.diw.de/de/diw_01.c.508843.de/forschung_beratung/projekte/projekt_hometeys/dieter/dieter.html</a></td>
</tr>
<tr>
<td>E2 tool</td>
<td>Regional</td>
<td>Residential and commercial buildings, personal vehicle and commercial transport, solid waste and agriculture</td>
<td>Simulation</td>
<td>Policy-makers</td>
<td>Can be required to: Ramona Mattix - <a href="mailto:rmattix@rdck.bc.ca">rmattix@rdck.bc.ca</a> or Ron Macdonald - <a href="mailto:ron.macdonald@stantec.com">ron.macdonald@stantec.com</a></td>
</tr>
<tr>
<td>EMPS</td>
<td>International</td>
<td>Power systems with a focus on hydro power</td>
<td>Simulation Optimization</td>
<td>Experienced energy system modellers</td>
<td>Commercial</td>
</tr>
<tr>
<td>EnergyPLAN</td>
<td>National regional</td>
<td>Entire energy system</td>
<td>Simulation</td>
<td>Researchers, consultancies, policy-makers</td>
<td>Free download from: <a href="http://www.energyplan.eu">www.energyplan.eu</a></td>
</tr>
<tr>
<td>GTMax</td>
<td>National regional</td>
<td>Dispatch of electric generating units and the economic trade of energy among utility companies</td>
<td>Simulation Optimization</td>
<td>Universities consultants, Power companies</td>
<td>Commercial</td>
</tr>
<tr>
<td>ICLEI tool</td>
<td>Municipal</td>
<td>Municipal buildings, vehicle fleet, public lighting, Residential, Commercial, Industry, Transport, Community Waste and Agriculture</td>
<td>Simulation</td>
<td>Consultancies, policy-makers</td>
<td>Download after the approval of the ICLEI from: <a href="http://www.iclei-europe.org/ccp/basic-climate-toolkit">www.iclei-europe.org/ccp/basic-climate-toolkit</a></td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
<td>------------</td>
<td>-----------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>LEAP</td>
<td>National regional</td>
<td>Entire energy system</td>
<td>Simulation</td>
<td>Research Institutes, Universities, SMEs</td>
<td>Free for developing countries Commercial for OECD countries</td>
</tr>
<tr>
<td>Markal/TIMES</td>
<td>National</td>
<td>Entire energy system</td>
<td>Optimization</td>
<td>Research Institutes, Universities, SMEs</td>
<td>Commercial</td>
</tr>
<tr>
<td>MESSAGE</td>
<td>Global</td>
<td>Entire energy system</td>
<td>Optimization</td>
<td>Experienced energy system modellers</td>
<td>Free/Simulators must be purchased</td>
</tr>
<tr>
<td>OSeMOSYS</td>
<td>National regional</td>
<td>Entire energy system</td>
<td>Optimization</td>
<td>Energy system modellers</td>
<td>Free download from: <a href="http://www.osemosys.org/getting-started.html">www.osemosys.org/getting-started.html</a></td>
</tr>
<tr>
<td>PRIMES</td>
<td>National</td>
<td>Entire energy system</td>
<td>Simulation</td>
<td>Experienced energy system modellers</td>
<td>It is not sold to third parties, but it is used within consultancy projects undertaken by NTUA (Athens)</td>
</tr>
<tr>
<td>URBS</td>
<td>National Local</td>
<td>Multi-commodity energy systems with a focus on optimal storage sizing and use</td>
<td>Optimization</td>
<td>Research Institutes Universities</td>
<td>Free download from: <a href="https://urbs.readthedocs.org/en/latest/">https://urbs.readthedocs.org/en/latest/</a></td>
</tr>
<tr>
<td>TRACE</td>
<td>Municipal</td>
<td>Passenger transport, municipal buildings, water and wastewater, public lighting, power and heat, and solid waste.</td>
<td>Simulation</td>
<td>Policy-makers</td>
<td>Free download from: <a href="http://www.esmap.org/node/add/tool-download">www.esmap.org/node/add/tool-download</a></td>
</tr>
<tr>
<td>WILMAR Planing Tool</td>
<td>International</td>
<td>Power system</td>
<td>Simulation Optimization</td>
<td>Energy system modellers</td>
<td>Commercial</td>
</tr>
</tbody>
</table>
A first element of classification is the geographical coverage of the analyzed system (local, regional, national or global). Table 1 shows that most of the available models (for example, DESSTINEE, GTMax, MARKAL/TIMES, OSeMOSYS, PRIMES, etc.) were designed to evaluate complex energy systems at national and supra-national scale, requiring very experienced users. Nevertheless, over the time the same models were also implemented and tested on regional and local energy systems, demonstrating their effectiveness also at smaller scales (Calliope, LEAP, OSeMOSYS, URBS, etc.).

Moreover, although most of the models represented in Table 1 focus on the whole energy system (Calliope, Markal/TIMES, Message, etc.) a big slice of them are focused on specific sectors. These “sectoral” models can refer, for instance, to district heating (Balmorel), to the electricity system with a focus on the penetration of renewable energy sources (EMPS, GTMax, WILMAR Planning Tool) while many others focus on buildings in order to promote and increase the number of “nearly zero-energy buildings - NZEB” by 2020 on the boost of the Energy Performance of Buildings Directive (TRACE).

Depending on the approach adopted, energy models can be divided into two main categories: simulation and optimization models. Simulation models estimate, parametrically, the response of the energy system for a given set of variables or policies and identify possible impacts and costs/benefits of the analyzed configuration (e.g. LEAP and Balmorel). The optimization models calculate the values that lead to the optimal configuration for all the system variables. The optimal configuration minimizes or maximizes a given objective function, for example, an economic objective function coinciding with the total discounted cost of the system. These models can take into account boundary conditions, in order to narrow the range of values assumed by variables (such as MARKAL/TIMES and OSeMOSYS). Models sometimes can be used for both simulation and optimization purposes (Codina Gironès et al. 2015), as for example EMPS, GTMax and Wilmar Planning Tool.

Furthermore, the models can be classified into bottom-up and top down models. The bottom-up models (such as MARKAL/TIMES and OSeMOSYS) are used to analyze the dynamics of the energy system, taking into account also the introduction of new technologies. The macroeconomic data are exogenous and therefore these models are not able to evaluate the effects of feedback on the economy of technological innovation. The top-down models (as, for instance, LEAP) are, essentially, general equilibrium econometric models which assess endogenously the response of the economic system for different political measures and scenarios. Because of their market-oriented approach, they provide a limited representation of the energy sector and lack of detail in the description of existing and future technologies, which are typically identified by aggregate functions for each economic sector. Therefore, the top-down models are useful in the analysis of the evolution of energy prices and macroeconomic variables, but not to compare the effects of different energy policies.

Although the high availability of models to support energy systems analysis and planning, their use is still scarce among policy makers and decision makers. This is mainly due to the general complexity of most of these models which need high levels of expertise to manage both the set-up phase and result analysis, as it is pointed out by the “target users “ column of Table 1. In particular, data gathering is often a difficult task dealing with the compilation of a very detailed energy balance for a reference year, due to the scarce availability of local energy data on the demand side (energy consumption per fuels and final demands), as well as on the supply side (delivery of fuels or transformed fuels to point of consumption).

The current challenge of model developers is to make available user-friendly and, where possible, open source decision support tools whose use goes beyond the scientific community and can be transferred to energy planners, policy makers and local administrators after a short training making. Some examples of more user-friendly models to support local administrators in the planning of medium-long term energy strategies are already available (e.g. 2050 Calculator, E2 tool, TRACE, etc.) and will be presented in the following section.
The use of decision support tools by local administrations: some examples

In Europe, local and regional governments generally have little knowledge of existing energy systems (Figure 3). In particular, very often they do not have the exact picture of the energy consumed by the main demand sectors (Residential, Commercial, Transport, Agriculture, Industry) and, in particular, by the publicly-owned buildings (governmental offices, schools, hospitals, etc.) or on the breakdown among energy commodities and final uses (electricity, natural gas, diesel, etc.).

A frequent and common concern is data availability: often there are no adequate statistics or databases at local scale (municipal and regional). Moreover, municipal energy plans and the related energy balances are compulsory only for larger cities (e.g. with more than 50,000 inhabitants, according to Italian Law n. 10/91). On the other hand, international networks promoting sustainability of energy systems among cities have had an important role in raising awareness of public administrators on the necessity to account for local emissions and, consequently, to have a precise knowledge of municipal energy consumption.

The great success achieved by the Covenant of Mayors initiative has boosted, all around Europe, the development of numerous Sustainable Energy Action Plans (SEAPs) inclusive of energy balances and CO₂ inventories covering key target sectors (buildings and transport, usage of renewable energies and CHP). First of all Italy, with 3164 signatories (CoM, 2015) representing 48% of the total cities and 1962 cities with an accepted SEAP.

Due to lack of knowledge and control of the energy consumption at municipal level, local administrators need to be supported in the identification of suitable strategies to reduce energy consumption, increase energy efficiency and promote the development of renewable energy, considering both technological and behavioral aspects. To this aim energy models can represent a valid support in setting up an energy system baseline and to derive short-term energy and climate strategies within long-term sustainable pathways.

Municipalities and regional governments rarely use analytical tools to support their decisions on energy and climate issues, although the scientific community has made available a large number of decision support tools, with different features and levels of expertise required.
Between the available tools, the Tool for Rapid Assessment of City Energy (TRACE, 2011) is a decision-support system designed to help cities to identify opportunities to increase Energy Efficiency (EE). TRACE was developed by the Energy Sector Management Assistance Program (ESMAP), a global technical assistance program administered by the World Bank, and was designed to involve city decision-makers in the deployment process. TRACE focuses on the municipal sectors with the highest energy use: passenger transport, municipal buildings, water and wastewater, public lighting, power and heat, and solid waste. It targets under-performing sectors, evaluates improvement and cost-saving potential, and helps prioritize actions for EE interventions. TRACE consists of three modules: an energy benchmarking module which compares key performance indicators (KPIs) among peer cities, a sector prioritization module which identifies sectors that offer the greatest potential with respect to energy-cost savings, and an intervention selection module which functions like a “playbook” of tried-and-tested EE measures and helps select locally appropriate EE interventions. TRACE has been deployed in twenty seven cities in Africa, Asia, Europe and Central Asia, and Latin America.

An easy-to-use tool for local administration is also the ICLEI Europe Basic Climate toolkit (ICLEI, 2015), which allows to collect and systematize all energy data and provides GHG emission inventories as final output. These inventories can help local governments to understand where emissions are released and which are the key priority areas and the achievements obtained by different reduction actions. For these reasons this tool is very useful to support the elaboration of Sustainable Energy Action Plans for those municipalities that have joined the Covenant of Mayors. It is based on Excel spreadsheets which are filled in with two categories of input data: Local Government Operations and Community Inventory. The first category takes into account energy consumption of municipal buildings, vehicle fleet, public lighting, water and sewage, while the other category considers the energy consumption in Residential, Commercial, Industry, Transport, Community Waste and Agriculture sectors (Salvia et al. 2015). Within the SEE RE-SEEties project, an ICLEI add-in tool was developed to support local administrations in calculating the input parameters of the ICLEI tool where data are missing using proxy variables and information made available by regional or national databases (Salvia et al. 2014).

Another example of user-friendly tool is the E2 Tool (E2 tool, 2015) used by local governments in British Columbia (Canada) to forecast energy and greenhouse gas emissions for their community, as well as to assess the impact of reduction measures. It is a spreadsheet based tool which can be used to develop forecasts of energy consumption and greenhouse gas (GHG) emissions for milestone years (2010, 2015, 2020, 2025, 2030) to 2050. The E2 tool can be used for any community-wide emissions where baseline data is available and has been used for residential and commercial buildings, personal vehicle and commercial transportation, solid waste and agriculture. It can also include industrial buildings if baseline data is available. The data input is characterized by freely available data, with the objective of minimizing specialized data sets because not all communities have detailed statistics or studies available. Key data requirements for the base model predictions include statistics on Canada population and housing data, Community Energy and Emissions Inventory (CEEI), estimates of the possible population growth. The tool accounts for both the impacts of population growth and other initiatives by higher levels of government, for instance to include increased fuel efficiency standards for passenger and commercial vehicles, and proposed building code and equipment improvements. Additional information that can be used in more customized settings includes housing forecasts, or estimates of changes in housing types, forecasts of commercial development and land use, actual or forecasted building permit data, demographic studies, etc.

Among the available energy-system models it is worth mentioning also the Swiss-Energyscope (Moret et al. 2014) an online platform developed by the Energy Center of EPFL (Ecole Politecnique Federale de Lausanne) with the aim to support decision-makers by improving their understanding of the energy system (Gironès et al. 2015). The online platform mainly consists of an energy calculator, enabling users to evaluate the effect of a list of possible choices on the energy future of the country. In particular, it shows the effect of the policy and investment decisions on final energy consumption,
total cost and environmental impact. The modelling approach is currently implemented within an online energy calculator for the case of Switzerland nevertheless it can be easily adapted to any large-scale energy system. An online wiki (https://it.wikipedia.org/wiki/Wiki) and a MOOC (Massive Open Online Course) allow interested users to acquire basic knowledge on the energy system and to be guided through the learning process and the use of the calculator itself.

The 2050 Calculator (Department of Energy & Climate Change, 2013) is a user-friendly model developed in the UK to simply visualize the effects of changing behavior on climate change. In particular, it lets citizens, students and also administrators to create their emissions reduction pathway. It is available in three versions to allow a range of audiences to explore the fundamental question of how the UK can best meet energy needs while reducing emissions. In particular, the user-friendly web-tool version is intended for a detailed look at the issue, the simplified My2050 simulation is for those who want an overview, while the full Excel version of the 2050 Calculator for experts is for those who want to look at the underpinning model. The 2050 Calculator was published by the UK Department of Energy and Climate Change but the adopted approach has been replicated also in other parts of the world.

Conclusions

Local and regional authorities are undoubtedly assuming a more and more strategic role in the achievement of national and international energy and climate commitments.

This review shows that a large variety of decision-support tools are currently available and sufficiently validated to support decision-making at local and regional scale.

The most recurrent barriers to the effective utilization of decision support tools in municipal and regional energy planning departments deal with the lack of common protocols to promote their widespread use, the multi-layer and often not integrated decision-making processes, their general low user-friendliness, the general lack of data and the scarce knowledge of current energy flows across the supply and end-use demand sectors.

A better link between all the actors involved in the planning processes, a stronger collaboration between the research community and local authorities as well as the participation of communities in inter-regional and transnational cooperation initiatives represent key drivers to increase the knowledge of energy systems and devise sustainable future paths with a holistic vision, fostering at the same time mutual learning through the exchange of good practices.

Nevertheless, it should be emphasized that energy systems sustainability cannot be pursued by a top-down policy approach, but requires an active engagement of citizens since the beginning of the planning process and across all its crucial phases. The current challenge is, therefore, to foster a transition towards local and regional sustainable energy systems in which “soft measures are an essential lever for the implementation of hard measures” (Energy Cities, 2012) in perfect agreement with the smart cities and communities paradigm.

References


Bottom-up modelling of continuous renovation and energy balance of existing building stock: case study Kočevje

Marjana Šijanec Zavrl, Gašper Stegnar, Andraž Rakušček, Henrik Gjerkeš
Building and Civil Engineering Institute ZRMK, Ljubljana, Slovenia
Corresponding author: Marjana Šijanec Zavrl, marjana.sijanec@gi-zrmk.si

Abstract: A dynamic bottom-up model of the building stock is developed and implemented in a case study of Kočevje urban region. In the model, national register of real estate is cross-linked to data from other registers, e.g. the energy performance certificates (EPC) and the subsidized energy renovation measures. Regular updates of the data in registers enable continual improvement of the model. The renovation potential is determined with respect to the age of building components after the last renovation, while the energy performance of the building stock is based either on the EPC for a particular building if available or on the energy indicators of corresponding building type from IEE EPISCOPE building typology and IEE RePublic_ZEB. Thus, the bottom-up model of the building stock (BuilS) enable a profound overview of the total heat demand, final energy use and CO₂ emissions of the entire stock.

In the case study Kočevje, various strategies for improving the buildings towards more sustainable ones are presented with projections to 2030. The strategies, reference and intensive renovation scenario, are compared with more ambitious strategy that the municipality is looking towards in the frame of Covenant of Mayors commitment. The bottom-up model was validated against the metered energy use of buildings connected to district heating. In the case study the model shows how the implementation of various strategies lead to different impacts and how the ambitious municipal plans are going to produce independence from fossil fuels by fostering the use of wood biomass as a locally available sustainable energy supply. The Kočevje case study analysis demonstrates, at the local level how a concept of increasing renewable energy sources utilisation and building energy efficiency stimulated by progressive measures can respond to low carbon society and sustainable energy self-supply challenges.

Keywords: modelling, renovation scenarios, building stock, region policies

Introduction

Slovenia accepted ambitious targets for deep renovation of existing buildings described in the national strategic documents. For example, National energy efficiency action plan 2014–2020, in short NEEAP 2020, (AN URE 2020) and Long-term strategy for mobilising investment in the renovation of national buildings stocks (DS SNEPS) the national target to improve energy efficiency (EE) by 20 % by 2020 is defined, in line with the requirements set out in Directive 2012/27/EU (Energy Efficiency Directive). The existing building stock represents the sector with the greatest potential for achieving energy savings. To meet the national EE target, a quarter of that building stock, or around 22 million m² of useful floor area, has to be renovated. The improved energy performance will reduce the energy consumption in buildings by almost 10 % in the period 2014-2020.

On the other side, many EU municipalities and/or regions joined The Covenant of Mayors (CoM), the initiative of the European Commission to sign a voluntary agreement to reach and exceed the goal of 20 % reduction of CO₂ emission by 2020 also at the local and/or regional level and to contribute to 20-20-20 by 2020 climate and energy policy targets. Thus, a number of various local and regional activities specified in the sustainable energy action plans (SEAPs) is complementing the national policies and measures.
The Kočevje region is one of the most naturally preserved areas of Slovenia and Central Europe. The forests cover more than 90% of the total area. The municipality started to work on sustainable energy policies systematically in 2008, when the local energy concept (LEK 2008) was adopted. It includes the analysis of existing condition in the field of energy use and supply (which emphasizes the public buildings) and possibilities of use of local renewable energy sources (RES). In the local energy concept the EE and RES targets in the region are defined and the action plan agreed. In 2014 Kočevje signed the Covenant of Mayors and started to prepare the SEAP aiming at significant reduction of energy related CO$_2$ emissions.

In the urban area of the city of Kočevje the prevailing way of building heating is district heating system, powered by wooden biomass and fuel oil. Most of the individual houses in sub-urban area use wood and fuel oil as a heating source for heating. Municipality plans to replace oil as a fuel source powering the district heating system with innovative cogeneration system with wooden biomass gasification process to considerably lower the carbon footprint from building heating, to increase local energy self-supply and to increase level of renewable energy sources in national power grid. Energy renovation of the existing building stock is ongoing, supported by national and municipal incentives for housing and public buildings. EE and RES measures on demand and supply side are being implemented to support the goal to reach almost zero emission Kočevje region.

Planning and monitoring of the impacts of variety of policies and measures in building sector has become a complex task in particular due to the fragmentation of the building stock and several data gaps. Usually, the top-down building models are used, taking into account the statistical data on the floor area per year of construction of the building stock diversified per building type (i.e. residential houses and apartment buildings; buildings for non-residential use). The weakness of such models is that they disregard or only roughly consider the actual condition of the building stock, which is a result of the actual renovation dynamics, characterized by the information on the renovation done and on the basic technical details of the implemented works on building elements, energy systems or on the building as a whole.

The research in this paper aims to develop a bottom-up model of the building stock in the Kočevje region by integrating publicly available databases and surveys, relevant for forecasting the impacts of climate and energy related policies and measures in the region. The scope of the study is to validate the bottom-up model of the building stock and to forecast the impacts of sustainable energy policies in the region through dynamic modelling of energy performance of buildings.

Modelling energy use in buildings is an important step towards designing and implementing policy measures related to energy savings in buildings. Swan and Ugursal (2009) reviewed available models for assessing the effects of energy saving measures (ESM, also referred to as energy efficiency measures, represent actions aimed at reducing energy demand in buildings) in the residential sector, and concluded that so-called bottom-up modelling of buildings is required to determine the impacts of new technologies. But on the other hand, a bottom-up model of the building stock typically comprises building physics modelling for calculating the energy usage of individual buildings, and extrapolation of the results to a region or a country (Mata et al., 2013).

Kavgic et al. (2010) reviewed selected bottom-up building stock models for energy use in the residential sector and proposed that they should: (a) estimate the baseline energy demand of the existing building stock; (b) explore the technical and economic effects of different CO$_2$ emission reduction strategies over time, including the impacts of new technologies; and (c) identify the effects of the strategies on the quality of the indoor environment.

In the framework of the Intelligent Energy Europe project TABULA (Loga et al., 2012) a building typology of existing dwelling stock was developed using different types of buildings and periods of building construction in each country. Later on the work on typology was upgraded and new schemes of renovation monitoring as well as modelling of energy balance scenarios were developed in the scope of EPISCOPE (2015) project, which consists now of 20 European countries. When dealing with
The presented bottom-up model enables to determine more accurately the status of the building stock in terms of energy performance characteristics. This is achieved by cross-linking publicly available databases on the building stock, national surveys on energy use in buildings and records on implemented subsidised energy efficiency measures as well as the data on the structure of energy supply. The integration of EE and RES measures on the demand and supply side of the building stock is demonstrated through the application of the bottom-up model in Kočevje region.

Methodology

Data sources

Several data sources were used in the bottom-up model of the building stock in order to ensure sufficiently accurate and comprehensive analysis of dynamic energy balance of the building stock in the region:

- Databases from Geodetic Administration of the Republic of Slovenia (GURS, 2015);
- Eco Fund (Eko sklad, 2015), Slovenian Environmental Public Fund;
- National energy efficiency action plan 2014-2020 for Slovenia (MzI, 2015);
- Statistical Office of the Republic of Slovenia: contains information on the number and area of completed dwellings (new construction, extensions, conversion according to the CC-SI classification), the number of demolished dwellings and others. (SURS 2015b);
- Intelligent Energy Europe TABULA (ZRMK, 2012a), EPISCOPE (Episcope, 2014), RePublic_ZEB (RePublic_ZEB, 2015);
- Register of Energy performance certificates (EPC, 2015);
- REUS - Survey of the energy efficiency in Slovenia (REUS, 2015).

The main sources for bottom-up modelling are the register of real estates (REN), the register of energy performance certificates (EPC register), the database of Eco fund subsidies and REUS survey (Figure 1). One of the biggest challenges is linking the energy performance related data of a particular building across all relevant databases, since each data source has been established separately throughout the past 8 years since 2007. REN register, managed by Geodetic Administration of the Republic of Slovenia (GURS), keeps complete (actual) data on the renovation of thermal envelope components up to 2008 with minor updates up to 2014. Eco fund keeps data of conferred national subsidies for thermal envelope components and building systems from 2008. EPC register was established in 2013 by the responsible ministry and covers up to date 3% of the building stock per building only. It stores the energy indicators and data on energy carriers per certified building. REUS survey is based on a poll that was conducted through interviews on 1006 households, regarding key areas of energy consumption in households and shows indicators on the status of the buildings and technical equipment of households as well as the building owners’ intention of modernizing buildings and systems (REUS, 2015).
Bottom-up model

A bottom-up building stock model (BuilS) is a spatially referenced parameterised per-building model developed with the purpose of determine the energy performance of the building and further build the energy balance of the building stock. The presented model addresses two main challenges: (1) having a precise and open bottom-up building model that is continually improving with new information on buildings (e.g. REN, EPC register and REUS) and (2) having a model that enables to adopt strategies of cities/regions/country for building stock renovation and shift towards sustainable energy supply.

The model uses “three layers” for calculation. The first layer is a long-term model of the building stock. It quantifies the expected future annual stock and reference floor area on the basis of the assumed past and future demand (Mzl, 2015), i.e. the assumed development in persons, persons per dwelling and reference floor area per dwelling, potential for (partial/full/deep) renovation, based on the assumption for renovation and new build rates. This layer of the model also follows the ageing development of each type/age segment of the stock, with predicted lifetime of building component and it’s technologies for heating and DHW, after which the building becomes the potential for renovation, based on the proposed scenarios of renovation rates for each age band (construction periods: 0-1945, 1946-1970, 1971-1980, 1981-2001, 2002-2008, 2009-to date) (ZRMK, 2012). According to these scenarios, the model identifies the adequate number of buildings for renovation, depending on the initial state before renovation (concerning thermal envelope components and heating systems) (Figure 2).

The first layer of the model considers four different initial buildings states – unrefurbished, partial, full and deep renovation (Figure 2). When considering possible renovation of buildings, different levels of renovation lead to the change of the initial state, e.g. a partly renovated building (roof renovated in 2008) can in the future be subject to full renovation (if renovation of a façade and boiler replacement are implemented) in order to reach the level of fully renovated building. The initial state of the building offers different potential for renovation, where four possible levels of the initial state are assumed (ZRMK 2012b):

- Unrefurbished: Based on the existing data, the building has not been subject to any renovation in the past; therefore, it has potential for renovation on all components of the thermal envelope (walls, roof, and windows) and technical systems. Unrefurbished buildings can be subject to partial, full and deep renovation.
- Partial Renovation: Based on the existing data, the building was subject to renovation of one or two building envelope components (walls, roof or windows) in the past, therefore the building has
potential to have one or two components of the thermal envelope (walls, roof or windows) and technical systems renovated. Buildings with partial renovation can be subject to partial, full or deep renovation.

- **Full Renovation**: Based on the existing data, buildings identified as fully renovated are of two types. First, the building was subject to renovation of two building envelope components (walls, roof or windows) in the past and technical system for heating, therefore the building has potential for renovation of only one component of the thermal envelope (walls, roof, and windows). Second, it has all three thermal envelope components renovated and has a potential for replacement of heating system. Due to limited potential the buildings in full renovation category can be subject to partial renovation only.

- **Deep Renovation**: the building has experienced major renovation works in the past, all building components of the thermal envelope had been renovated, heating system replaced and thus the building is considered to have low energy demand for space heating. Deeply renovated buildings have no further potential for renovation.

![Figure 2 - Process of modelling the energy renovation in the BuilS model (1st and 2nd layer).](image)

In the BuilS model, one of the above initial state was attributed to each building in the case study, according to available energy related data on exact building in data sources described in 2.1. Renovation rate in the model is a weighted rate according to the renovation level (Figure 2) and expected energy savings, respectively. For the purpose of this work, the model adopts Slovenian national strategy renovation rates (Mzl 2015a), i.e. maximum annual renovation rate in the building category is adopted from reference and intensive building renovation scenarios.
The second layer of the model is an energy and emission layer. The input data are the results from the first layer and additional data sources concerning heating systems and energy carriers in buildings. If the building is connected to a district heating network or the energy carrier for heating and domestic hot water is known from an EPC the information is allocated to the particular building in the model. The rest of the building stock is assumed to be supplied by statistical distribution of energy carriers (Figure 3). In the model the energy use of the building is either estimated on the basis of building typology ((EPISCOPE, 2015), (RePublic_ZEB, 2015)) or allocated from EPC register, if an EPC is available for particular building.

The last third layer takes into account scenarios for sustainable renovation of the building stock (at local, regional or national level), e.g. more intensive renovation rates in specific year due to increased incentives, increased share of building connected to district heating network due to network expansion in a city district.

Figure 3 - Share of used energy carriers for space heating (left) and domestic hot water (right) for single-family houses (SFH), multi-family houses (MFH) and non-residential buildings (NR).

Results for Kočevje case study

Modelling of initial state

The bottom-up model was applied on Kočevje city region, which includes residential and non-residential buildings. The vast majority of past renovation rates of thermal envelope components were deducted from two main sources – Register of Real Estates (REN 2014) (Table 1) and Eco fund subsides (Eco fund 2009-2014) (Table 2). Weighted renovation rates according to useful surface area for case study is presented in Figure 4.
Table 1 - Share of recorded renovation measures on thermal envelope in the municipality Kočevje according to the total useful surface area of the building stock (REN, 2014).

<table>
<thead>
<tr>
<th>Year</th>
<th>Walls</th>
<th>Roof</th>
<th>Windows</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0.59 %</td>
<td>1.59 %</td>
<td>1.10 %</td>
</tr>
<tr>
<td>2001</td>
<td>0.54 %</td>
<td>1.19 %</td>
<td>0.64 %</td>
</tr>
<tr>
<td>2002</td>
<td>0.71 %</td>
<td>1.06 %</td>
<td>0.95 %</td>
</tr>
<tr>
<td>2003</td>
<td>0.96 %</td>
<td>1.56 %</td>
<td>0.78 %</td>
</tr>
<tr>
<td>2004</td>
<td>1.30 %</td>
<td>0.94 %</td>
<td>1.30 %</td>
</tr>
<tr>
<td>2005</td>
<td>1.52 %</td>
<td>1.14 %</td>
<td>1.37 %</td>
</tr>
<tr>
<td>2006</td>
<td>1.71 %</td>
<td>1.70 %</td>
<td>1.72 %</td>
</tr>
<tr>
<td>2007</td>
<td>0.53 %</td>
<td>0.39 %</td>
<td>0.34 %</td>
</tr>
<tr>
<td>2008</td>
<td>0.63 %</td>
<td>0.20 %</td>
<td>0.42 %</td>
</tr>
<tr>
<td>2009</td>
<td>0.15 %</td>
<td>0.11 %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>2010</td>
<td>0.64 %</td>
<td>0.22 %</td>
<td>0.24 %</td>
</tr>
<tr>
<td>2011</td>
<td>0.54 %</td>
<td>0.15 %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>2012</td>
<td>0.91 %</td>
<td>0.10 %</td>
<td>0.11 %</td>
</tr>
<tr>
<td>2013</td>
<td>0.02 %</td>
<td>0.00 %</td>
<td>0.02 %</td>
</tr>
<tr>
<td>2014</td>
<td>0.00 %</td>
<td>0.00 %</td>
<td>0.00 %</td>
</tr>
</tbody>
</table>

Table 2 - Share of subsidised energy efficiency measures on thermal envelope in the municipality Kočevje according to the total useful surface area of the residential building stock (Eco fund, 2009-2014).

<table>
<thead>
<tr>
<th>Year</th>
<th>Walls</th>
<th>Roof</th>
<th>Windows</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>0.07 %</td>
<td>0.00 %</td>
<td>0.61 %</td>
</tr>
<tr>
<td>2010</td>
<td>0.39 %</td>
<td>0.05 %</td>
<td>0.93 %</td>
</tr>
<tr>
<td>2011</td>
<td>0.26 %</td>
<td>0.02 %</td>
<td>0.94 %</td>
</tr>
<tr>
<td>2012</td>
<td>0.35 %</td>
<td>0.00 %</td>
<td>0.34 %</td>
</tr>
<tr>
<td>2013</td>
<td>0.27 %</td>
<td>0.07 %</td>
<td>0.15 %</td>
</tr>
<tr>
<td>2014</td>
<td>0.13 %</td>
<td>0.33 %</td>
<td>0.13 %</td>
</tr>
</tbody>
</table>

Figure 4 - Renovation rate for single- and multi-family houses of subsidised measures in municipality Kočevje according to the useful surface area.
For case study Kočevje, the results show (Figure 5) the biggest potential for energy savings in the residential sector for buildings built in the period 1946 – 1980. It also shows that a majority of buildings built after 1980 have not been subjected to any renovation yet and it is expected the considerable share will be subjected to renovation in the near future, since the life-time period of construction element is 30 years.

Figure 5 - Initial potential for renovation for single-family houses (left), multi-family houses (middle) and non-residential buildings (right) in Kočevje with respect to total useful floor area.

The initial potential for renovation of buildings in Kočevje is presented on Figure 5 with support of Geographic Information Systems (GIS) (Figure 6), which offers the opportunity to characterize building stocks in some systematic dimensions using geo-referenced information for buildings.

To this goal, we developed an application with Google maps API, which enables a powerful way of presenting the energy balance of the building stock. For case study Kočevje, an application was developed which shows several aspects of the building stock, resulting from the analyses. Figure 6 shows the potential for renovation of thermal envelope’s components. The buildings where roof, façade and windows where potential for renovation are marked as red with radius 3. Buildings with 2 components for renovation have radius 2, and buildings with potential for renovation of 1 component – radius 1. Enhanced image reveals that the vast majority of the buildings have a big potential for renovation on thermal envelope.

Figure 6 - An overview of the current state of the building stock with GIS-based approach and Google Maps API (left: all buildings in Kočevje; middle: buildings with potential for renovation on thermal envelope; right: enhanced overview of the potential).
Validation

Well thought out validation is essential when describing the physical processes in buildings and dealing with the complexity of building energy modelling. Ideally, the performance of a building energy simulation tool (excel model, analysis software) should be validated against measured data from a real building. However, such data is not always available as the urban indoor and outdoor environments too complex to be instrumented sufficiently. So as stated by Zmeureanu et al. (1987), sufficient testing should be conducted to assure that the probability of failure is sufficiently low to be acceptable.

The differences between theoretical and actual energy consumption are thought to arise from a multitude of factors. Theoretical energy use is based on normalized conditions, based on quasi steady-state method, such as indoor temperature of 20 degrees in the vast majority of buildings and heating degree days, heating of the entire floor area, infiltration rate assumed on the basis of the characteristics of the construction elements, etc. The way that occupants use the building in reality probably differs from these assumptions. According to several authors (Gill et al., 2010, Santin, 2010, Haas et al., 1998), occupant behaviour and lifestyle is thought to be a key factor in the discrepancy between theoretical and actual heating energy use and is correlated to energy performance itself.

To this point, ‘BuilS’ bottom-up model was validated against the measured energy consumption of the buildings connected to the district heating network in Kočevje. In the period from 2008 to 2014, 196 buildings (residential and commercial) have/had been supplied by local biomass district heating network in the city of Kočevje. The district heating network has gradually been expanding during this period, thus the number of connected buildings increased, while on the other hand there had been some disconnections as well. A comparison of the normalized measured energy consumption and simulated energy use in the BuilS model for the observed period is presented on Figure 7. The objective was to observe if the predicted energy consumption for heating and domestic hot water falls within the range of accepted deviation.

Figure 7 - Comparison of the measured and modelled energy consumption.

In the period between 2009 and 2014 the average deviation is 4.83 % which is below acceptable targeted 10 % deviation. Only for the first year 2008 the deviation is higher – 15.4 %, the difference can be attributed to many factors. The key factor that must be taken into account for the first year only is the optimization of the local district heating substations. Performance in the first year of operation of the biomass district heating network might not be fully optimized yet, thus consumption was a bit higher.
Building stock renovation scenarios

First two observed scenarios, reference and intensive scenario are taking into account as well the share of used technologies, which follows the national strategies and local state and limitations. Share of heat pumps and biomass boilers is slowly increasing, while share of energy carriers oil and liquid gas is decreasing. Third scenario strictly follows real local policy and is considered as an upgrade of a reference scenario, regarding the renovation rates on thermal envelope. From municipal plans for the expansion of biomass district heating network it was deducted which exact buildings in the future are going to be connected to the grid. This scenario presents a realistic applicability of the model on-site and demonstrates its potentials, e.g. measuring the effects of local policy on carbon footprint.

Key results are presented in Figure 8 and Figure 9. For the building stock in case study Kočevje the total energy need for heating is structured according to the energy rating of buildings (Figure 8), whereas energy rating of particular building is based on its energy need for heating (Qnh), obtained either from EPC or from building typology. In the base case of 2015, the estimated total final energy of the residential building stock in Municipality Kočevje is 116.406 GWh/year, with an emission factor of 0.232 kg CO₂/kWh. This gives a specific total average energy need for heating of 161 kWh/m²/year and a specific emission level of 37.4 kg CO₂/m²-year.

![Figure 8 - Total energy need for heating for the case study Kočevje.](image)

Reference scenario, intensive and local policy scenario give substantial reductions in annual total heat demand and CO₂ emissions compared to 2015. The total average energy need for heating decreases from 161 kWh/m²-year to a level of about 111 kWh/m²-year in 2020, and to around 66 kWh/m²-year in 2030. With the given changes in the energy mix, and an overall CO₂ emission factor increases from 0.232 to 0.258 kg CO₂/kWh in trend scenario, although considerable improvements are recorded in annual CO₂ emissions. These are later reduced from 37.4 kg CO₂/m²-year in 2015 to 26.3 – 26.8 kg CO₂/m²-year in 2020, 15.8 – 17.5 kg CO₂/m²-year in 2030.

Despite the significant growth in building stock reference area by 16.1 % from 2015 to 2030, these emission intensity improvements yield significant overall emission reductions (tons CO₂/year) of
around 25% in 2020 and 46 – 51% reductions in 2030, compared to the 2015 level, where buildings emit 18,567 tons of CO₂ emissions. With respect to the estimation of carbon emissions in 2008, the later were reduced from 24,000 tons of CO₂/year to lower than 19,000 CO₂/year.

All the observed scenarios (reference, intensive and local) show great promise in the fulfilling the regional contribution to national goals for the reduction of final energy use and GHG emissions. According to policy targets and EPISCOPE benchmark levels (5% reduction in 2020 and 30% reduction in 2030 according to 2015) are met in both the observed years – 2020 and 2030. The primary energy is reduced in all scenarios, one of the focal points is the impact of the local energy policy implementation in practice, where the expansion of local district grid is considered in 2016, 2020 and 2025. The primary energy is reduced for 14%, 33% and 44%, respectively.

![Figure 9 - Carbon emissions for the building stock case study Kočevoje as calculated using BuilS model.](image-url)

**Discussion and conclusion**

The goal of this study was to show that a bottom-up model enables to set a correct baseline regarding energy use of the existing building stock. Such a model is a powerful tool to evaluate the impact of public policies on buildings, in particular those related to climate and energy. A bottom-up building stock model (BuilS) has been used to estimate the energy consumption of the entire building stock (domestic and commercial building sector) over the observed period. The modelling follows three layers: (1) identification of the potential, (2) building renovation and (3) applying different sustainable scenarios. One of the most significant barriers for development of such a detailed model is the availability and applicability of databases that contain data related to buildings energy efficiency.

The simulated impact of the policies depend significantly on the type of available data in terms of their quantity and quality, as the later can improve the level of accuracy of the model. The relevant data derive from various sources, e.g. surveys, public databases and various reports on implemented policies eg. incentives. For the BuilS model, the main data sources are the register of real estates, the register of energy performance certificates, the database of Eco fund subsidies and REUS survey.
The paper points out the importance of regular monitoring of the building stock through continually upgraded databases with new entries regarding building renovation on the level of each building. The main shortcoming of available databases is the data integrity on energy efficiency at a building level, since the renovations implemented after 2008 (a nationwide survey on buildings for REN was carried out in Slovenia in 2007) have not been systematically recorded (EPISCOPE, 2015). Furthermore, REN does not have complete data on energy carriers that buildings use for heating or domestic hot water. However, the lacking data on heating systems and energy carriers exist in several independent records (information of regular inspection of heating systems, air conditioning systems and energy management entries) but have not been properly structured yet.

Overall, the validation results indicate that BuilS model predicts the energy use well. A case study Kočevje was simulated and validated through measured energy consumption of the buildings connected to district heating network. The total average deviation between simulated and measured annual energy consumption in the observed period between 2008 and 2014 is 6.34%. In case study Kočevje the application of BuilS model showed the reduction of CO₂ emissions for 25 % (beyond the 20% target from CoM).

The model BuilS can be adjusted to individual building stock, regardless the geographical area, if building typology and corresponding energy related characteristics (eg. energy rating). The usual problem of energy modelling of building stock is incomplete data on the energy supply at a building level. For modelling at least the structure of the energy supply in the geographical region is necessary. The accuracy of the modelling increases with availability of the data on the supply side, eg. connection to district heating networks, regional preference of a particular energy carrier, eg. biomass. Modelling energy balance of a city/region is interesting for stakeholders from several points of view: (1) modelling the baseline of energy use and emissions, (2) planning and monitoring of sustainable energy policies in the region, (3) optimizing EE and RES investments according to the climate and energy targets. The development of energy performance certification of buildings and accelerated preparation of SEAPs under Covenant of Mayors facilitate the acquisition of better quality data for bottom-up modelling of continuous renovation and energy balance of existing building stock.

Acknowledgements

This work is based on the results of the European project IEE EPISCOPE (www.episcope.eu), partly financed by the European Commission within the European programme “Intelligent Energy Europe” (IEE), under the coordination of the Institut Wohnen und Umwelt GmbH, Germany and project IEE RePublic_ZEB (www.republic.org), partly financed by the European Commission within the European programme “Intelligent Energy Europe” (IEE), under the coordination of Italian Thermotechnical Committee Energy and Environment.

References


Presented posters
Establishing a method to perform a BPS - Building Performance Simulation.

Nowadays to say that a building has a good energy performance, is necessary to develop a BPS to have an approach to the real energy performance. And it’s accessible to anyone with scientific and technical knowledge interested in energy issues.

Steps to follow in way to do a BPS:

1. **External Data - Environment**
   - Analyze the external conditions of the region where the building is located.
   - *Outside Temperature*
   - *Global Horizontal & Diffuse radiation*
   - *Wind speed & Direction*

2. **Modelling**
   - Model the building simple as possible form, without detailing thoroughly geometry; This to facilitate the calculations to the calculation engine.
   - *Orientation*
   - *Paritions*
   - *Number & use of each zone*

3. **Simplified Building Data - Construction**
   - Enter only the information necessary to make a first approximation of results.
   - *Envelope & U-value of all opaque and transparent building exterior surfaces*
   - *Shading of all glazing components*

4. **Simplified Systems & Equipments**
   - Enter only the information necessary to make a first approximation of results.
   - *Interior conditions*
   - *Internal Gains*
   - *Occupancy schedules*
   - *HVAC set-points*

5. **Analyzed Behaviour**
   - The final results are obtained once we have the desired performances of the building or we reach the desired performance in schedules and energy consumption.

6. **Detailed Building Data - Construction**
   - Once made the analysis, if have a good performance, the envelope can be detailed or try different construction systems or materials.

7. **Detailed Systems & Equipments**
   - The final results are obtained once we have the desired performances of the building or we reach the desired performance in schedules and energy consumption.

8. **Final Results**
   - Benefits provide by a BPS parametric analysis if steps follow?
   - *Cost savings in energy consumption and cost of installation*
   - *Improved internal comfort*
   - *Reduction of greenhouse gases*
   - *Increased energy sustainability*
   - *Improved energy performance of the building*

(Hansen & Radosevic 2004) Taking care of these issues is in principle the responsibility of the person who uses the simulation model to predict what will happen in future reality.

BPS is applicable to any region of which it is desired to know their energy behavior, through the analysis of the different typologies of common or important buildings in the region. As an example obtaining energy consumption in kWh/m² multiplied by the square meters total of this typology.

References:
Assessment of energy-related refurbishment strategies via Bayesian-Network Modelling

Sebastian Botzler, M.Sc. botzler@tum.de
Dipl.-Ing. (FH) Christina Dotzler, M.Eng. christina.dotzler@tum.de
Konstantina Mavroudi, M.Sc. nadia.mavroudi@gmail.com

Model/Theoretical Background

Introduction

Portfolio managers, building owners, public institutions, or real estate companies increasingly ask for economic and efficient ways to develop holistic refurbishment strategies to modernise their building stock efficiently. A potential tool should provide a wide range of features, like:

- ranking of necessary refurbishment measures
- selection of buildings that have a certain energy-saving potential
- weakpoint analysis of the building stock

The effectiveness of energy-saving measures in general and the specific energy-saving potentials, which result in the generalisation of those measures and energy-saving potentials, is a key aspect. In data which just represent deterministic values of a small scope of specific buildings are still not taken into account. The presented methodology is part of a research project, which was started in 2013 and will be finished in 2016 [3]. It offers refurbishment-suggestions for large building portfolios with only a small amount of data on the buildings characteristics. The method will be first implemented at university campuses but is planned to work also with building data in urban quarters and whole regions.

Methodology

In order to reflect the existing uncertainties in recommending refurbishment strategies, a probabilistic approach has been chosen. In the proposed project a Bayesian-Network (BN) has been implemented in the process of a BIM-aided and building information exchange. The method is to be implemented at university campuses and is planned to work also with building data in urban quarters and whole regions. The BNs combine principles from graph theory, probability theory, computer science, and statistics. For example, a BN can be used to quantify the probability of a particular energy savings. BNs are also used for decision making which is the case in the presented project.

Implementation/Case Study

Data generation

In order to generate the data for the BN, various refurbishment measures and their specific energy saving potentials have been simulated with a stationary building simulation tool in order to calculate the impacts of the measures. The generation of these measures depends on the specific characteristics of buildings and types. The approach in this state of the art shows that there are more than 200 variables that have been calculated and are in the process of being implemented in the model.

Damages on building components

Other data that have been used as an input for the BN are the impacts of damages on the building construction. First findings for example indicate that structural elements like exterior walls with moisture penetration have a higher heat transition than dry walls. In combination with other data, like the construction age of the material, the condition of building elements can be classified and the energy saving potential of refurbishment measures (e.g. insulation of the ext. wall) can be calculated with a certain evidence in the BN-model.

Results

The BN-model will help to identify the highest energy saving potential as well as the most sustainable and cost effective refurbishment measures. It provides an overview of the risks and uncertainties due to assumptions and calculations related to existing buildings. In combination with a quick check tool for rapid building survey and actual energy consumption data the BN-model is able to create efficient and sustainable modernisation strategies for various building types and usages.

Case Study

Additionally to the simulated data, the probabilistic model will be loaded with data of existing refurbishment projects and implemented and validated on the building stock of the Ludwig Maximilians-Universität München. The associated research program HoEff-CIM [3] focuses on automated and eased energy efficient refurbishment of universities and colleges.

Outlook

The next steps in the project are planned as:
- the development and set-up of a database,
- sensitivity analysis and optimization measures
- the extension of the model within climate scenarios
- detailing of the model and practical implementation in urban and regional scale

References:


Figure 1: heat energy consumption in specific university buildings [1]

Several studies and databases focus on these questions and offer a wide overview over various building age classes, including typical construction characteristics, age-specific weaknesses and potentials, which result in generalisation and energy-saving potentials. Uncertainties in data which just represent deterministic values of a small scope of specific buildings are still not taken into account. The presented methodology is part of a research project, which was started in 2013 and will be finished in 2016 [3]. It offers refurbishment-suggestions for large building portfolios with only a small amount of data on the buildings characteristics. The method will be first implemented at university campuses but is planned to work also with building data in urban quarters and whole regions.

Figure 2: simplified bayesian network model of window refurbishment [authors model] [2]

Figure 3: Simulated heating-energy demand for specific refurbishment measures, after the measures were individually implemented for each building age class

Figure 4: Model potential for different refurbishment measures based on the window refurbishment model [2]
Design considerations for the integration of battery storage systems in UK communities

Aiakaterini Chatzivasileiadis
Welsh School of Architecture, Cardiff University, UK
E-mail: ChatzivasileiadisA@cardiff.ac.uk

Introduction
Considering the large use of fluctuating renewable energy sources in the coming years, electrical energy storage systems will increasingly be introduced in the built environment, as a flexible solution to reduce temporary mismatches between supply and demand. The principal aim of this study is to investigate the implications of the integration of battery storage technologies on the architectural design of buildings. The investigation focuses on battery integration in residential buildings, emphasising on their spatial requirements. The footprint (m²), volume (m³), mass (kg), as well as the levelised cost of electricity (LCOE, €/kWh) for different battery technologies are compared to electricity supply activity of a group of houses in the UK. This study addresses sustainable regional approaches to building energy demand and supply, and low carbon technologies.

Methodology
The calculation of the nominal capacity of the battery system is based on winter's peak electricity consumption values, so as to allow for sufficient storage capacity all year round. It is assumed that energy efficiency improvements, electric heating and electrification of transport by including one electric vehicle in each house take place. Electricity consumption data for 2013 were provided by Intertek [1], which were then extrapolated to 2030. For this, a scenario is considered range and thus a range for the batteries' effective capacity for UK households was derived. Details for these calculations are provided in [2]. The houses run on AC power are assumed to be powered by renewable energy sources and able to operate on island mode. Therefore, 4 days of autonomy[3] for off-grid use [3] were assumed. The batteries' nominal capacity was estimated considering their efficiency, depth of discharge (DoD) and cycle-life [4], as shown in Figure 1, as well as the temperature factor, aging factor, design margin, autonomy period, the daily self-discharge factor and the DoD/BAC/I converter's efficiency. To calculate the nominal capacity of the batteries (Figure 2), the formula below was used:

\[ C_{nom} = \frac{P_{peak} \times 1000 \times 24 \times \eta_{BAC} \times \eta_{DoD} \times \eta_{cycle} \times \eta_{temp} \times \eta_{aged}}{2 \times \Delta C_{day}} \]

where:
- \( P_{peak} \) is the nominal power of the battery for four autonomy days
- \( C_{nom} \) is the effective capacity
- \( \eta_{BAC} \) is the cycle-life factor
- \( \eta_{DoD} \) is the DoD factor
- \( \eta_{cycle} \) is the temperature factor
- \( \eta_{temp} \) is the storage's aging factor
- \( \eta_{aged} \) is the battery's self-discharge factor
- \( \Delta C_{day} \) is the autonomy period in days

The parameters that have been used in order to estimate the footprint, the volume and the LCOE of the battery technologies are illustrated in Figure 3.

The LCOE of the battery, \( C_{LCOE} \) (€/kWh of electricity generated over lifetime of technology), is calculated using the formula below:

\[ C_{LCOE} = \frac{C_{capital} + C_{O&M} \times N_{cycles}}{C_{LCOE}} \]

As this work deals with ranges for the input data, i.e. electricity consumption and parameters in Figure 3, the outputs of the calculations presented in the next section are also depicted in ranges, considering a low range and a high range for the design aspects.

Results and discussion
The results of the investigation regarding the footprint, the volume, the mass and the LCOE for the nine battery technologies are presented in Figure 4.

It is apparent from Figure 4 that although some technologies have similar nominal capacity values (Figure 2), not only can they have different footprints, but also different volume and mass. LCOE, Pb-acid requires the highest nominal capacity and is by far the most unfavourable technology in terms of footprint, volume and mass. It has a relatively low LCOE, which makes it an economical option. NiCd is just behind Pb-acid as regards the nominal capacity and the mass. It has a big footprint especially when the maximum spatial requirement is assumed and medium volume has a high LCOE, making it an expensive storage option that might not be applicable for groups of 5 or more houses. NiMH has medium capacity requirement and has little applicability, being able to serve up to 1 or 2 houses depending on their daily electricity consumption. It also has a quite big footprint especially in the case where the minimum spatial requirement has been considered. It has medium volume and mass and the highest LCOE, making it the most expensive option over its lifetime. Li-ion ranks second in terms of nominal capacity requirement. It is among the top three technologies regarding footprint and ranks second in terms of volume and mass when the maximum energy density and specific energy values are assumed. Li-ion, like NaS and Zn-air, has medium to low LCOE assuming a great reduction in investment cost by 2030 due to R&D. NaS has medium nominal capacity requirement and might not be applicable for one house. It ranks either first or second as regards the footprint and is among the top three technologies as regards volume and mass. NaS has high nominal capacity requirement and is a medium option regarding footprint. It ranks third or fourth in terms of mass. LCOE varies from NiCd and NiMH and it has very low LCOE. V-Redox has medium to low capacity requirement and it is an unfavourable technology regarding its footprint. Its assumption of the lowest LCOE assuming low investment cost by 2030. Zn-air has medium to low capacity requirement and it is a medium option regarding footprint, ranking fourth if the minimum value for spatial requirement is assumed. It has medium mass values and just like V-Redox, it is unfavourable in terms of volume. Zn-air requires the lowest nominal capacity. It is one of the top three technologies regarding footprint and the top technology in terms of volume and mass, exhibiting the highest energy density and specific energy among all battery technologies. It also has one of the lowest LCOE values.

Conclusions
This study presented design aspects regarding battery storage integration in buildings. In 2030, in terms of footprint, Li-ion, NaS and Zn-air are the top three technologies exhibiting the smallest footprint and Pb-acid the last one having the biggest footprint. As for volume considerations, in the case where the minimum energy density values are considered, high range, Zn-air, NiS and NiMH are the top three technologies exhibiting the smallest volume. In the case where the maximum values are considered (low range), the top three are Zn-air, Li-ion and NaS. In both cases Pb-acid, V-Redox and Zn-air are the least favourable technologies regarding their maximum volume. Regarding mass, in the case where the minimum specific energy values are considered (high range), Zn-air, NaS and NaNiC are the top three technologies exhibiting the smallest mass. In the case where the maximum values are considered (low range), the top three are Zn-air, Li-ion and NaS. In both cases Pb-acid and NaCd are the least favourable technologies having the biggest mass. In terms of LCOE, Zn-air, NaS and V-Redox are the top three options, while NiMH and NaCd and Pb-acid rank last.
Development of a High Resolution Atmospheric Urban Scale Model for Energy Applications in the Built Environment

D. Bouris¹, A.G. Triantafyllou², A. Krestou³, E. Leivaditou³, N. Zoumakis³ and K.G. Rados³

¹Lab. for Innovative Environmental Technologies, School of Mechanical Engineering, National Technical University of Athens, 15780 Athens, Greece, dbouris@fluid.mech.ntua.gr
²Lab. of Atmospheric Pollution and Environmental Physics, TEI of Western Macedonia, 50100 Kozani, Greece
³General Section, ATEI of Thessaloniki, Central Macedonia, 57400 Thessaloniki, Greece

Background
A building's energy consumption is dependent on its own design and construction and on its interaction with environmental parameters such as temperature, solar radiation, wind speed etc. Although these parameters are closely related to meteorological conditions, they are also affected by the building's surroundings and the building itself. This is a complex interaction that may be observed in varying degrees in both rural and urban settings and, with increasing sophistication of building energy management systems, it must be taken into account when gathering information. Mesoscale numerical weather prediction models may be used but they usually provide information at a spatial resolution in the order of kilometers so when detailed information is required at the building scale, an urban scale model is necessary.

Approach
The work currently being performed is part of a coordinated effort involving numerical weather predictions at the meso-scale, computational fluid dynamics (CFD) modeling at the building scale and experimental measurements of wind speed and temperature profiles at a number of locations above the city of Kozani in northern Greece (Figure 1). In the work presented here, the TAPM weather prediction model (Hurley, 2000) has been applied over a 30x30km region up to a 300m spatial resolution with five (nested) grids. A SODAR anemometer and a meteorological temperature profile have been used to measure profiles of wind velocity (up to 300 m above ground) and temperature (up to 600 m above ground) (Triantafyllou et al, 2015) at two locations within the modeled region. Finally, CFD calculations are performed over a 700x750m part of the city at a spatial resolution of 5 m with the basic shapes of individual buildings modeled in position from GIS software and included as solid boundaries (Figure 1) for the solution of the Reynolds averaged Navier-Stokes equations on a Cartesian grid.

The CFD calculations are performed using a second order upwind scheme for the convection terms and the SST turbulence model. The code has multi local refinement capabilities and a number of turbulence modeling options (k-ε, k-ω RNG, k-ω SST), which were not implemented here. Instead, focus has been on the inlet boundary conditions and their accurate representation of the region's meteorological conditions.

Regional Effects
Proper definition of the boundary conditions for an urban scale modeling effort is imperative. These boundary conditions are highly mesoscale—and thus regionally—dependent while also being very demanding in terms of compatibility with the numerical procedure. Although mesoscale numerical weather prediction data has the potential to provide this information, the computational requirements are most often not compatible with a design effort that includes multiple parametric studies and calculations. Here, the ultimate goal is to develop a numerical tool that can be used to provide representative discrete atmospheric conditions at the building scale, from which in information regarding the thermal and wind environment around the building may be drawn. These representative conditions may be correlated to real time conditions predicted by mesoscale numerical weather modeling without directly using the mesoscale results for the CFD calculations.

Results
In Figure 2, the COST 710 guidelines (Cenedese et al., 1997) have been used to create wind velocity profiles that correspond to the six classic atmospheric condition classes of Pasquill, depending on the absolute value of wind speed and on the heat exchange between the air and the ground. In Figure 3, calculated wind profiles at position (2) of Figure 2 are presented along with the results of measurements and mesoscale calculations. The profiles have been calculated using the velocity profile (E) of Figure 2, which corresponds to stable conditions, and applying it from four different directions (north, south, east and west). The effect of the approaching fetch is obvious in the southern direction where the largest difference in the boundary layer development is observed due to the denser urban environment south of the measurement point (2) (see Figure 1).

Figure 4 shows velocity and temperature profiles calculated using two different boundary conditions. The first (COST Inlet) implements the parametric procedure suggested by COST action 710 (Cenedese et al., 1997) and the second (TAPM Inlet) is an interpolation of the mesoscale results to the CFD grid. Comparison of both calculations with experimental measurements is good and suggests that the parameterization is an adequate procedure for creating boundary conditions for CFD environments.

In Figure 5, contours of pressure along with wind speed vectors are plotted in the area where the experimental measurements took place for neutral atmospheric conditions and two different wind directions. Pressure differences and wind speeds around the building where measurements took place differ significantly for the two different wind directions. The same level of differences arise when the wind direction is retained and the stability condition changes.

Conclusions
Design for energy applications in the built environment requires building scale information of environmental parameters such as wind velocity and temperature, which are highly dependent on the regional microclimate. Here, mesoscale numerical weather predictions, experimental measurements and building scale CFD have provided for the development of a numerical procedure that will enhance this design process, facilitating the inclusion of regional environmental parameters.
BACKGROUND

The Welsh School of Architecture has designed and built Wales’ first low carbon energy prototype house. The Solcer House is capable of exporting energy to the national electricity grid for the first time. This is an attempt to meet tough new targets for zero carbon housing. The UK Government has set a target for achieving zero carbon housing by 2016.

AFFORDABLE SYSTEMS APPROACH

The Solcer House’s unique systems approach to designing buildings, for the first time, is a hybrid solution combining solar and renewable energy and reduced energy demands, to create an energy positive house at an affordable cost. The Solcer House is located in the Cardiff area of Bonny Down, and has been designed and built as a model for housing standards. The house was completed in 18 weeks using local supply chains.

LOW ENERGY CONSTRUCTION

In order to reduce the energy demand, the house was built with high levels of thermal insulation and efficient air-tightness. It was an innovative energy efficient design which included low carbon cement, structural insulated panels (SIPs), external insulated membranes, triple glazing and solar panels (PV) and low energy ventilation system. The innovative design was to reduce the embodied energy in the building construction, as well as reducing the operating energy over its lifetime.

INNOVATIVE ENERGY SYSTEMS

The energy systems include solar generation and battery storage to power both the central heating, ventilation, hot water system, and the electrical power system, which includes appliances and LED lighting. In winter, space heat is provided by passing external air through the solar panels to heat the radiator panel system (THS) and a mechanical ventilation heat recovery unit (MVHR), and then delivered to the rooms. The system also incorporates photovoltaic panels and battery storage. The house uses grid electricity supply when the PV - battery system is not adequate. This predicted energy performance is 10% autonomous, with a 1.7 grid-export-to-input energy ratio.

RESULTS

The predicted energy performance is 10% autonomous, with a 1.7 grid-export-to-input energy ratio.

SUPPLY CHAIN

The components of the building have been selected, as far as reasonably practicable, from Welsh manufacturers and suppliers, and the house will use Welsh robust construction technologies. The low carbon systems have been designed to be affordable and replicable, for local developers to build houses using market available technologies. This systems approach aims to use very low amounts of energy to provide a comfortable environment for building occupants.

PROJECT LEADERSHIP

The project leads by the Welsh School of Architecture in partnership with UCL, as part of the SOLCER and LCBE Projects.

SOLCER Project

The aim of the SOLCER project is to implement combinations of existing and emerging low carbon technologies through a systems-based approach in order to optimise the use of energy at the point of generation.

LCBE Project

The Low Carbon Built Environment project brings Welsh academics and industry together to reduce CO2 emissions associated with both the built environment.

The programme ensures the end-user environment in the sector, from component to building to region. It also includes all stages of the building environment process, from planning through design and construction to operation.

For more information on the Solcer House, see the website, Solcer, for information see the Solcer Project site at the university.

ACADEMIC PROJECTS

For more information on the Solcer House, see the website, Solcer, for information see the Solcer Project site at the university.

The house was built as part of the Low Carbon Research Institute (LCRI) Low Carbon Built Environment (LCBE) project, funded by the UK government and the Welsh government, as part of the Low Carbon Research Institute (LCRI) Low Carbon Built Environment (LCBE) project, funded by the UK government and the Welsh government.

The house was built as part of the Low Carbon Research Institute (LCRI) Low Carbon Built Environment (LCBE) project, funded by the UK government and the Welsh government. The house remains at the heart of the development of new zero carbon housing future. This building demonstrates the ability to achieve zero carbon energy demand at a domestic scale which we hope will be replicated in other areas of the UK and the UK in the future.
PassiveHouse (NZEB) Craftsmen Course for new buildings and refurbishment

INITIAL SITUATION

The building sector with its share of about 40% of Europe’s total energy consumption constitutes a main starting point for energy efficiency measures. Due to the directive 2002/91/EC of the European Parliament and of the Council on the energy performance of buildings (EPBD 2010), which intends from 2020 onwards only “nearly zero energy buildings” – and therefore all but passive-house standard for new buildings – as well as due to the increasing high quality energy refurbishment of existing buildings, it is expected that the demand for skilled crafts (wo)men will increase dramatically.

In Austria, a study (Plate et al.) showed a potential for passivhouses and appartments of up to 65% of all new built housing units, i.e. about 31,000 units per year until 2018. Also in the course of a analysis of training demands in the field of energy optimized buildings and from numerous talks to decision makers in the field of energy efficient buildings, it became clear that there is a strong shortage in training courses for the implementing crafts (wo)men. The need for new course concepts has further been supported by the directive 2002/91/EC of the European Parliament and of the Council on energy efficiency (EEF 2012), which emphasizes the relevance of training and education in all levels of energy efficiency and stipulates a strict obligation to report the national implementation activities to the EC, including sanctions in case of non-compliance.

PROJECT GOALS

In the EU supported project CERTCRAFT (ISO/EVET) the elimination of this shortage through the development of an internationally available modular training course for craftsmen in the field of highly energy efficient buildings was the main aim. Performed between December 2013 and December 2015 within the Programme “Leonardo da Vinci, Transfer of Innovation” the new training concept should further develop the multiple awarded PassivHouseCraftsmenCourse (PHCC) to the PHCCplus thus fostering the quality assurance in the passive- and nearly energy houses sector in the future.

In addition to that, the increase of career opportunities, especially for Eastern Europe crafts (wo)men, the promotion of transnational mobility of work force through ECVET-Credits (European Credit System for Vocational Education and Training) and the personnel certificate according to ISO 17024 for the international recognition of the training were important. The training of certified (wo)men, who will be situated at local training centres for further trainings in the local language, should massively support the dissemination of energy efficient building and foster the life-long learning aspect in the partner countries.

The project partnership comprises six relevant organisations from Austria, Hungary, Romania and Switzerland. During the two years project duration the goal has been to train in all these countries apprentices in 5 trains and educational staff including a 200-page handbook in “craftsmen language” should be developed in English, German, Hungarian and Romanian. Furthermore the learning outcomes orientated course concept had to be prepared for the ECVET and to be in line with a concerted certification scheme according to ISO 17024.

METHODOLOGY

The training course has been designed for all relevant crafts of the NZEB – nearly zero energy buildings / passivhouse sector, as well as developers and housing cooperatives to be applied as in-service training building upon the corresponding apprentices training as well as the first education in Secondary Colleges of Engineering.

It also allows personnel certification according to ISO 17024 and the integration into the ECVET which is regarded as the basis for international acceptance and relevance of the course. In this certificate, all competences that were acquired during the course are documented and an appropriate amount of ECVET points is assigned.

The training outcomes oriented curriculum is structured along the four main modules “Basics”, “New buildings”, “NAMIC” and “Renovation” comprising all together 17 learning modules, the main contents of which deploys into a knowledge – skills – competences – matrix to foster the ECVET process in the fields of energy efficient buildings craft(wo)men.

In favour of an integrated approach where crafts get knowledge, skills and competences of “foreign” crafts too in order to better communicate on the building site thus avoiding lots of structural damage in the future strong focus has been laid on the interface optimisation between the different crafts. Therefore according to the needs of the practice the PHCCplus offers specialisation modules for new buildings and refurbishment.

The course material is focusing on “real world - construction site knowledge”, besides numerous detailed chapters on outer walls, windows, roofs and chimneys, by means of seven mostly Hb- or klime-ta ilcertified family houses, apartment and office buildings (in massive, light and mixed construction methods), the passive or nearly zero energy building process is explained from the basement to the roof top. Another important part is the module “NAMIC in passiv/ nearly zero energy houses” providing a sound overview on all systems for heating, cooling and water heating, including plenty of up-to-date information. In addition to that, an e-learning platform has been established, besides an extensive literature data base, interactive demonstrations graphics and other content, for two of the seven passivhouses prior constructionus, including explanations of the crafts interfaces and a complete photo documentation of the construction process is available.

One big focus of the course implementation are training workshops with experienced practitioners using 1:1 demo walls where crucial passivhouse details are practically installed by the participants themselves. Another important aspect is the visit of construction sites where the newly learned content can be seen in real applications.

RESULTS

The brand new PHCCplus course has been tested in the partner countries by more than 230 participants, 69 trainers have been trained and the unique craftsmen-handbook containing more than 270 pages in four modules is available in German as well as in English and with adaptations in Hungarian and Romanian language – which means that the initial project goals have fulfilled and been exceeded. Furthermore a concerted certification scheme according to ISO 17024 as well as the learning outcomes orientated preparation for the ECVET – European Credit System for Vocational Education and Training is available in German and English.

OUTLOOK

In Austria the PHCCplus+ will be modular bookable via four 24 teaching units blocks on the “free market” at the WIG Storia from the beginning of 2016 as well as from 2017 at the WIG Vienna. In Switzerland the new course will be integrated in the regular further educational schedule of Campus Sursee from beginning of 2016 within the framework of the well known, well established Interreg standard. In Hungary and Romania the next courses are planned in cooperation with the national passivhouse associations as well as being integrated into the schedule of some secondary technical schools.

CONTACT

IG PASSIVHAUS PLUS
Dipl.-Ing. Herbert Heingässner
Bauakademiestraß 6, A-8020 Graz
Tel.: +43 (0)664 / 3441644
E-Mail: herwig.heingassner@ig-passivhausplus.at

PARTNER ORGANISATIONS

IG Passivhaus Plus (Graz, AT) - Leopoldina
Wittenkind, Verein für Bildung und Nachhaltigkeit (Salzburg, AT)
Campus Sursee, Bildungszentrum (24h Sursee, CH)
Passivhouse Association of Romania (Hermanos-Crist, RO)
Passivhouse Association of Hungary (Passivhaus+, HU)
Fakultät Bau BT (Sciences, Building, HU)

REFERENCES

Plate et al., Multiplikatorischer und Fachwissensteilwechsel des Passivhauses in Österreich, Wien, April 2016

www.certcraft.eu
ABSTRACT

The poster presents the concept of the Training school of the COST Action TU1104 “Smart Energy Regions”. The subject was retrofitting of existing buildings and open public and communal places within the settlements. The aim was to show some possibilities and options for improving the environmental and energy performance of existing neighbourhoods at a regional scale, which were the topics of discussion and research during the training school. Different levels of retrofitting were the subject of consideration from urban to building one.

Methodology for training included lectures-theoretical knowledge and practical work. Practical work entailed the following methodological approaches: analysis of the existing situation; design of retrofitting concepts; modelling and simulations; comparative analyses. Four groups of trainees were formed and each chose a particular focus as a topic of its design-based research which resulted in concrete proposals for improvements on urban and building levels. Results of their work were presented on posters and digital presentations.

POSTERS’ AUTHORS:

Prof. Dr. Aleksandra Kristl-Furundžić
Branka Antonić, researcher
Faculty of Architecture, University of Belgrade, Belgrade, Serbia

Prof. Dr. Aleksandra Đulić
Technical support: Mirta Vojvodić, PhD student
Tijana Vojvodić, PhD student
Branka Antonić, PhD student

TRAIINES:

Era Corina Boasa, Researcher and Architect, Welsh School of Architecture, Cardiff, United Kingdom
Sara Collen, PhD student, Queen’s University Belfast, United Kingdom
Nickolas Dascos, PhD student, University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria
Liacio Felice, Student, Norwegian University of Science and Technology, Norway
Klaudia Gudziol, PhD student, University of Wroclaw, Poland
Laura Gugol, PhD student and teaching assistant, Karlsruhe University of Technology, Germany
Ljiljana Jeremic, PhD candidate, Novi Sad University of Science and Technology, Serbia
Vesna Kamenska, Econometrician and master student, “Ss. Cyril and Methodius”, University of Skopje, Bulgaria
Jafina Mihaljević, Researcher, Technical University of Denmark, Denmark
Antonio Manuel Cibrian, School of Technology, Valencia, Spain
Marta Rodriguez, PhD student and researcher, ENEA, Italy
Ricardo Escribano, Architect, University of Valladolid, Spain
Vanesa Sallach, Architect, University of Bilbao, Spain
Magdalena Szajner, Architect and PhD student, Poznan University of Technology, Poland
Pavel Vítovec, Architect and PhD student, Technische Universität München, Germany
Irena Zlatković, Assistant and Architect, University of Novi Sad, Serbia

THEORETICAL & PRACTICAL WORK

The course covers theory associated with:
- Retrofitting – urban design;
- Retrofitting – building design;
- Modelling and simulations; procedures of simulations of energy performances of different design solutions using appropriate software;
- Monitoring with a distinct regional approach

PROGRAMME

Theoretical classes

THEORETICAL PRESENTATIONS

Presentation 1: Aleksandra Đulić – The focus of the lecture was on retrofitting of communal open spaces in megapolis. The research which was done in Belgrade, Serbia has been presented. The simulations have been done by UNIST and ENTECH.

Presentation 2: Stojanov Lukić – The lecture explains basic concepts of modelling and simulations of RE. Examples, specific scenarios have been presented as well as multidisciplinary simulation concept which implies different aspects of building management and retrofitting.

Presentation 3: Giuseppe La Ferla – The lecture focused on net-zero architectural strategy for existing dwellings. The construction components and issues are of building envelope focusing on the energy performance were presented.

Presentation 4: Aleksandra Kristl-Furundžić – Net-zero envelope is a blueprint to connect existing buildings into energy efficient and reduce the consumption of conventional energy options and thus energy demand and emissions.

Presentation 5: Luis Benajam – The lecture explains the use of a building performance simulation through light building technology. Many examples have been used to understand the basic principles in building performance simulation is presented, as well as studies and results related to buildings’ retrofitting.

Presentation 6: Giuseppe La Ferla – The lecture has been focused on real case of study in Milan, analyzing the energy use and historical aspects of the intervention and evaluate energy performance of existing buildings.

Presentation 7: Stojanov Lukić – The lecture presented research trends in introduction of advanced monitoring, data analysis and new technologies and strategies for evaluating buildings' energy use and urban environment.

Presentation 8: Luis Benajam – The lecture explores the main case of the design of a building for energy efficiency, thermal and environmental benefits. This paper reflects on the ways which are more environmentally friendly.
Review and Results of Early Stage Researchers Training School
INTEGRATED APPROACH TO RETROFITTING EXISTING DWELLINGS
Belgrade, April 20-23, 2015

MAIN GOAL
The main goal of the Training School is to offer an opportunity to show how retrofitting of neighbourhoods can contribute to energy and environmental improvement of regions in a different context whilst enabling attendees to interact with researchers from across Europe.

FINAL RESULTS
All trainees were organized into four research groups during practical classes. Each group chose a specific focus on the general topic of the training school. Thus, each group developed specific research, which was presented in the form of the final presentation.

RESULTS / presented by groups:

Group 1:
"RETROFITTING PRINCIPLES FOR SUSTAINABLE URBAN DESIGN"
- L. Felus
- E. Costa Rossas
- V. Skaličkin
- M. Sopyma

Group 2:
"SCALABLE SOLUTION OF RETROFIT PROJECT ON TYPICAL APARTMENT LAYOUT"
- N. Salhi
- M. Žegar
- S. Cullen
- M. Rashdževski

Group 3:
"SOLAR CAPTURE SYSTEMS AS RETROFITTING SOLUTION FOR THE ENVELOPE"
- S. Jurdić
- V. Knežević
- A. Galletti
- A. M. Oliveira

Group 4:
"INTEGRATED APPROACH FOR RETROFITTING AT THE FLAT ROOFS AT 21ST BLOCK"
- L. Gogorje
- I. Novi
- A. Sotropić Nikolić
- M. Štefanić
Developing an optimisation tool for solar thermal system dimensioning in Lithuania

Andrius Jurelionis¹, Rokas Valančius¹, Eugenijus Perednis²
1 Kaunas University of Technology, Faculty of Civil Engineering and Architecture, Studentu st. 48, S137 Kaunas, Lithuania
2 Lithuanian Energy Institute, Laboratory of Renewable Energy, Breslaujos str. 3, Kaunas 44403, Lithuania
andrius.jurelionis@ktu.lt

Small-scale solar thermal domestic hot water systems in Lithuania can produce up to 523 kWh per year per one square meter of solar collector area. The expected payback period of these systems is approximately 10 years. However, the number of solar water heating systems (SWH) installed in the renovated multi-family buildings is quite limited.

Simplified optimization tools for solar collector area selection, volume selection for the accumulation tank, installation costs and payback period estimation are required for promoting SWH systems for domestic hot water (DHW) production in multi-family buildings on a regional scale.

Analysis of DHW consumption, solar irradiation and expected heat output was performed in this study and the tool was proposed for preliminary analysis of SWH systems integration in renovated multi-family buildings connected to district heating network.

**Methods**

The potential of SWH was estimated by using the DHW usage data from 15 multi-family buildings in Kaunas, expressed in monthly energy demand in kWh. The average consumption of DHW of temperature approx. equal to +55°C in the analysed buildings was 2.47 m³ (95.1%) per month and was lower compared to cold water consumption 3.86 m³ (38.1%) per month. Annual total annual irradiation in Kaunas city (58°32’N / 25°06’E) is equal to 884.8 kWh/m² which was the value used for performance simulations of SWH systems. High efficiency flat plate collectors (optical efficiency of collector ε = 80%) were selected for the simulations. The other parameters used for modelling SWH systems are presented below.

- **Life span, years**: 20
- **Specific fuel costs, EUR/kWh**: 8.07
- **Specific electricity costs, EUR/kWh**: 0.44
- **Initial capital, % of cost**: 25
- **Required investment, % of cost**: 1.5

Simulation software "T'SOL 5.0 Pro" was used for SWH systems performance evaluation as well as financial analysis of SWH system alternatives. Typical scheme of SWH systems was selected for the study.

![Diagram](image1)

Figure 1. SWH performance estimation chart comprising DHW usage per average apartment, optimal area of solar collectors and storage tank, required investment (without design costs) and payback period of the solar thermal system for multi-family buildings in Lithuania.

The entry point of the chart is based on average monthly DHW consumption which is followed by selection of solar fraction for DHW. This is the parameter which can be selected by the decision maker as an additional input, namely the percentage of annual energy demand for DHW which will be covered by the SWH system (values from 50% to 100% were analyzed). Active surface area of solar collector, storage tank volume, expected system efficiency as well as required investment are obtained as a result. The payback period of the selected system can be obtained by knowing the percentage of subsidies for SWH system installation (values of 0% to 100% were used in the chart). An example for such selection is provided in the Figure based on the input and output data (Table below).

<table>
<thead>
<tr>
<th>Step No</th>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Average monthly DHW usage</td>
<td>2.47 m³</td>
<td>Efficiency of SWH system</td>
<td>40-60%</td>
</tr>
<tr>
<td>2</td>
<td>Solar fraction for DHW</td>
<td>50%</td>
<td>Storage tank volume per apartment</td>
<td>30 L</td>
</tr>
<tr>
<td>3</td>
<td>Surface area of solar collectors per apartment</td>
<td>1.5 m²</td>
<td>Required investment</td>
<td>270 Euros</td>
</tr>
<tr>
<td>4</td>
<td>Subsidy</td>
<td>40%</td>
<td>Payback period</td>
<td>6.6 years</td>
</tr>
</tbody>
</table>

**Conclusions and discussion**

Analysis of domestic hot water consumption data showed that the average DHW demand for multi-family buildings in Lithuania is equal to 2.47 m³ per month. According to the meteorological data for solar irradiation, collector area of 1.7 m² and 90 l of heat storage tank volume per apartment are required to meet 50% of the annual energy needs for DHW production.

20 cases were simulated by using the "T'SOL 5.0 Pro" software to obtain relations between major parameters required to optimize systems for DHW applications in multi-family buildings in Lithuania. SWH performance estimation chart comprising DHW usage per average apartment, optimal area of solar collectors and storage tank, required investment and payback period of the solar thermal system was developed as a result.

The chart can be used by decision makers as a quick estimation tool for SWH installations in multi-family buildings. It may contribute to promoting SWH applications in multi-family building sector. Development of similar tools for different countries and climates could contribute to promoting renewable energy applications on a global scale.

It is important to note that the chart and data provided in this study is based on DHW consumption in the existing buildings in Lithuania, however the optimization procedure is solely based on simulation results. Numerical calculations show high potential of SWH application for DHW production in multi-family buildings and the data from existing buildings should be included in future studies to evaluate the difference between the results of the simulations and actual data from case studies. At the moment there is still lack of operational installations of this type equipped with monitoring systems to perform such an analysis.
**Energy Efficient Campus**

HoEff-CIM (Campus Information Modeling)

**Model/ Theoretical Background**

Introduction

This project (currently in progress) shows how to support universities in creating a climate-neutral campus by reducing demand and improving efficiency, based on the example of the campus of the Ludwig-Maximilians-Universität München (LMU).

To this end, refurbishment concepts will be developed that take account of the interactions that affect sustainability (economics, environmental and social aspects, technological quality, process quality) and combine them in an energy master plan for the LMU. The tools needed for energy and thermal assessments and the methods for efficient building operation in the form of an energy management system will be developed and refined and/or adapted to the university's needs.

Fields of action for refurbishment concepts have been identified based on an analysis of the current state and then examined in the context of the different interactions affecting sustainability prior to combining them in an energy master plan in consultation with the LMU.

The necessary tools will be developed in parallel and adapted to the needs of the university. Essential work aspects include, to begin with, ascertaining means of reducing the necessary survey data, the depth of the required detail, the evaluation of information and integration in the operation of the LMU (quick check tool, reference room method, energy report, building factsheet).

A phased energy management plan with various stages will then follow and its feasibility tested in pilot projects prior to overall implementation.

**Issue**

From the point of view of building physics (which is the main part of the TU München), all opaque and transparent components will be considered by their construction age.

Caused by the difficulty of the detection of the U values (heat transition coefficient: W/m²K) the team tries to find dependencies regarding the modernization measures.

The aim is to realize at least the German energy standard EnEV 2016 or even a nearly zero energy standard.

**Methodology**

Already determined U values and wall structures are taken from literature to compare different modernization measures to achieve low energy needs.

**Implementation/Case Study**

**Case Study**

All U values depending on their age will be collected. In addition all characteristic track structures will be registered.

Maximal possible savings on the energy demand per structural element and per building age will be simulated by using the ZUB Helena software.

Reasonable retrofit concepts will be created and will be shown in a data table in combination with an economical and ecological evaluation. This data table can be used by the property administration to create suitable retrofit concepts.

**Results**

Figure 2 shows first results of the ZUB Helena simulations. The energy demand of existing buildings according to their age is shown (blue beams). The orange line presents the entire retrofit according to EnEV 2016 (German Energy Saving Regulations). The green line also shows the entire retrofit according to nearly zero energy standard.

It illustrates the high energy saving potentials of older buildings.

For example: The energy saving potential of buildings built till 1918 according to the final energy demand is from 55% (EnEV 2016) to 63% (nearly zero energy standard).

The main goal of this project is to determine the refurbishment potentials of several buildings by their construction age. Through this regions can be valued by their energy consumption and complete refurbishment concepts can be calculated.

**Outlook**

The influence of structural damages on the energetic condition of the building envelope will be considered during the further procedure of this research project.

Furthermore the dependence of the building age on the possible savings will be determined.

**Partners**

- University of Applied Sciences Munich
- Ludwig-Maximilians-Universität München
- BROCHIER Consulting + Innovation GmbH
- ASSMANN Beratung + Planen GmbH

---

Figure 1: Model of the Representative LMU Building

Figure 2: final energy demand (kWh/m²a) according to the building age and energy standards

Institute of Energy Efficient and Sustainable Design and Building
Archistr 21, 80333 München, http://www.energiplansung.tum.de, Tel.: +49 (0) 89 239 23990

This poster is presented at the Smart Energy Regions International Conference, Cardiff, UK, 11th and 12th February 2016. The conference is funded by the COST Association through the COST Action TU1104 Smart Energy Regions.
Applications of PCM in building technologies

Potential applications of PCMs in building products & technologies

Oliver Kinnane¹; Dervilla Niall¹; Richard O’Hegarty²; Roisin Hyde¹; Maria Browne²; Sarah McCormack³;

¹: Architecture at SPACE, Queens University Belfast, Northern Ireland.
²: Department of Civil Engineering, Trinity College Dublin, Ireland.
³: Centre for Manufacturing Technologies and Innovation, University College Dublin, Ireland.

Phase Change Materials (PCM) have the potential to provide step-change innovations in building construction products and integrated power generating technologies. This poster presents research into a selection of potential applications of PCM for use in buildings. Research undertaken under the umbrella of three COST actions; TU1104 (Smarter Energy Regions), TU0802 (Next Generation of Cost Effective Phase Change Materials for increased energy efficiency in renewable energy systems in buildings) and TU1205 (Building Integration of Solar Thermal Systems) forms the basis of this study. The IMPRESS project funded by the Horizon 2020 framework program aims to provide innovative prefabricated modules for the recladding of medium to high-rise buildings dating from the middle of the last century, and today require renovation to prolong their lifetime. (http://www.project-impress.eu)
Some aspects of the smart region concept

Ákos Nemcsics
Research Group for Materials and Environmental Science, Óbuda University,
Tavaszmező utca 17, 1084 Budapest, Hungary,
e-mail: nemcsics.akos@kvk.uni-obuda.hu

Abstract: In this paper, the smart region concept is investigated. We are dealing, the size of a smart region. How can its borders determined. What is the relation between the administrative region and a smart region. Furthermore, we are dealing with the question of the size and the interactions among the regions. The discussion is extended with case studies.

Scaling invariance: There are some patterns in the nature and also in built environment, showing identical characteristic, independently from the magnification. These patterns are described in a mathematical form of self-affine and fractal formalism as well. They are characterized by fractured dimension. Determination of this directly in case of exact geometry, or by boks counting method in case of statistical size and shape.

The settlements, developing in self-assembled manner, this pattern is frequently observable.

Layout of the town Abony, in Hungary.

Scaling concept: In the nature, there are scale dependent and independent phenomenon and patterns as well. Some properties are dependent from the characteristic length in different ways.

In the built environment, there are such patterns also, which are not grow automatically with the growing of the object size.

References:
Á. Nemcsics: Some Aspects to the Pollution Reduction Related with Built Environment; Obuda University Bulletin, vol 3 (2012) pp 1-12
Á. Nemcsics: Some aspects to the smart region concept using the example of Szajk subregion; to be published in Obuda University Bulletin

The size vs. sequence number graphs for Vasvár regions, in Hungary.

This poster is presented at the Smart Energy Regions International Conference, Cardiff, UK, 11th and 12th February 2016.

The conference is funded by the COST Association through the COST Action TU1104 Smart Energy Regions.
The use of solar cadastre as an energy-planning tool at regional scale: estimation of PV potential, demand coverage and effects on the electricity grid infrastructure

David Moser¹, Armin Costa², Marcello Petitta³, Matteo Giacomo Prina¹, Roberto Monsorno²
¹Institute for Renewable Energy, EURAC Research, Viale Druso 1, 39100 Bolzano (BZ), Italy
²Institute for Remote Sensing, EURAC Research, Viale Druso 1, 39100 Bolzano (BZ), Italy
*Phone: +39 0471 055527; Fax: +39 0471 055699; E-mail: david.moser@eurac.edu

INTRODUCTION: In the past decade, the photovoltaic sector has experienced an unprecedented growth at worldwide level also thanks to various incentives schemes. This has led to visible positive effects such as lower electricity prices in some countries, partial coverage of energy demand in households / commercial buildings / industries, reduction in CO₂ emissions, new jobs in the renewable energy sector, new source of income or savings for local municipalities, etc. Nonetheless, the PV sector has also been subject to speculation, conflicts in terms of visual impact and fears for grid operators due to the intermittency in production. In this work, we present a methodology to assess the PV potential at roof level through a high-resolution solar cadastre where the architecture allows for the integration of different PV technologies and the development of complex computational tools. The method for the calculation of the solar irradiation considers the contribution of absorption due atmosphere and clouds, possibly accepting real-time values. It is thus possible to map the potential at district, municipality, regional level and it allows on one hand public bodies (municipalities, local authorities) to integrate energy spatial planning in their policies and on the other hand, the grid operators to assess how much PV could be installed at secondary and primary grid level. In the analysis, the method is applied to the Province of South Tyrol, in Italy, where the roof PV potential of more than 1 GW could cover almost 50% of the local electricity demand.

POLICY MAKERS/PLANNERS

<table>
<thead>
<tr>
<th>Thresholds (kW/m²)</th>
<th>area no flat (ha)</th>
<th>area flat (ha)</th>
<th>average H flat (kW/m²)</th>
<th>average H flat (kW/m²)</th>
<th>Pe (MW)</th>
<th>Electricity (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1200</td>
<td>1200</td>
<td>1100</td>
<td>1000</td>
<td>900</td>
<td>800</td>
<td>700</td>
</tr>
<tr>
<td>800-1000</td>
<td>600</td>
<td>500</td>
<td>400</td>
<td>300</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>&lt;800</td>
<td>200</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>With/without filters</td>
<td>300</td>
<td>200</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>Total area</td>
<td>1000</td>
<td>800</td>
<td>600</td>
<td>400</td>
<td>250</td>
<td>125</td>
</tr>
</tbody>
</table>

The PV rooftop potential in South Tyrol, for areas with H>1200 kW/m² is of 1.35 GW, considering a module efficiency of 15% (see also Moser 2014 and table above). This value could cover 50% of the existing electricity demand of the region (1.5 TWh over 3 TWh). The potential is higher than the 2050 target set by the local government (Ruffini 2011). However, actual growth (3 MW/year) puts the achievement of the targets under threat (see Figure 4).

CONCLUSIONS

The solar cadastre is a multilevel/multistakeholders tool for the development of a city/regional/national solar strategy. In this specific case, we have analysed the data from the solar cadastre of South Tyrol (a region situated in the North of Italy, 520,000 population).

Considering a 15% module efficiency, the PV rooftop potential is 1.35 GW, corresponding to a PV power per capita of 2.6 kW/person (see Figure 7 and 8). Specifically, the public building potential is of 55 MW (0.1 kW/person) and 287 MW (0.6 kW/person) for the industrial/commercial buildings. With the technologies of today, PV could cover 50% of the existing electricity demand.

The data can be used to evaluate novel concepts such as:
- Planning of nearly zero/positive energy districts
- Setting targets for PV at city level and analyse high penetration scenarios
- Inform DSO about the PV potential at district/city/regional level to plan grid reinforcement or implement smart grids solutions

REFERENCES

[references listed]
Assessment methods (AM) are a challenge:

- Need reliable results to evaluate energy performance, energy saving measures and to identify energy key factors of buildings to improve the regional built environment
- Demand of a quick and easy-to-use AM for a benchmarking process with different point of view: e.g. building, local building stock, regional built environment
- Conflict: Simple building AM are easy-to-use, but limited in their amount of information and model flexibility - the opposite holds for complex AMs

Buildings are complex – the next challenge:

- Heterogeneity of buildings increases this conflict and the assessment complexity
- Heterogeneous according to diverse construction types, designs, HVAC-systems, building use and occupant behavior
- Complex buildings need more comprehensive AM to fully consider their individual characteristics
- AM of a building stock should consider individual key factors of a building to improve local and regional energy performance and impact

The model – a further point to discuss:

- Uncertainty (UN) is introduced by input parameters and model assumptions
- Uncertainty & sensitivity (SN) measures cause huge efforts for the estimation
- Demand of statistical methods to consider UN, SN and to show a possible range of the results

Referenceroom-Method (RRM):

The RRM is a simplified approach of a whole-building simulation. The RRM could be described by using typical rooms only for energy and thermal behavior calculations, followed by the accumulation of each energy result considering specific floor space demands. The well-known and validated EnergyPlus engine is used as calculation core.

- Decreases model complexity and runtime significantly
- Offers opportunity for the implementation of extensive statistical methods

Building energy demand = \sum_{\text{for each occupancy}} \text{one referenceroom}

\sum_{\text{floor space demand of each occupancy}}

Statistical methods:

- Monte Carlo Simulation Technique and Sobol-Sequences for sampling
- Allows to address uncertainty and input parameter variations
- Allows estimation of mean values, distribution and standard deviation
- Decreases necessary number of simulation runs

Sensitivity indices and measure of importance:

- Qualitative: standardized regression coefficient
- Quantitative: 1st order (SI) and Total-Sensitivity indices
- Allows a ranking of important parameters

Software architecture for integration of the Referenceroom-Method (RRM):

- The RRM requires a powerful IT-infrastructure to handle the huge datasets needed for the calculation
- To manage and to analyse the data over an internet interface, a software system is built
- Data Mining is going to be integrated to efficiently compute the similarity between rooms

Integration of efficient software tools is possible
- Compute the similarity between rooms
- Generating a mathematical model based on energy and building data

Supported by:

- Federal Ministry for Economic Affairs and Energy
- PTJ
- EnOB
- Smart Energy Regions

This poster is presented at the Smart Energy Regions International Conference, Cardiff, UK, 11th and 12th February 2010. The conference is funded by the COST Association through the COST ACtion TU1004 Smart Energy Regions.
ENERGY EFFICIENT MEASURES FOR EXISTING AND NEW BUILDINGS IN MACEDONIA

ABSTRACT: There is an imperative demand for low-cost, energy-efficient housing in Republic of Macedonia. Macedonia is not rich with energetic resources and the annual energy import represents 10% of the total energy consumption. Repair of existing buildings incorporating thermal insulation materials in the building envelope, as well as construction of new energy efficient buildings requires special consideration on the type of insulation used, the thickness of the insulation layer, the position and the manner of installing the insulation. Proper application of thermal insulation is one of the most effective energy conservation measures for residential buildings and the most effective in reducing life cycle greenhouse gas emissions.

New wall systems have been built and approved with in-situ measurements, and a new earthship green house has been designed. The first passive house in Macedonia that spends only 10 kWh/m² annually has been built 5 years ago. Investors are becoming more confident with EE technology and the designers are becoming more comfortable incorporating EE measures and materials into designs. Hopefully, public awareness of depleting conventional energy resources will heighten, and with a mutual collaboration of the industry and all other key factors, European targets will be provided in Macedonia soon.

DESIGNS FOR ENERGY EFFICIENT REPAIR OF 14 BUILDINGS IN SKOPJE CITY CENTER

Thermographic measurement of old buildings in Skopje city center was performed with camera Testo 875 11. Measures for energy conservation and improvement of energy efficiency are recommended in the strengthening designs: insulation layers on the walls, roofs and floors, new windows, new heating systems, solar panels etc. (personal photos of T. Samardziska)

NEW APPROVED SOLUTIONS FOR NEW DESIGNED BUILDINGS

NEW WALL SYSTEM “FRAGMAT-NZ”

<table>
<thead>
<tr>
<th>Building</th>
<th>U-value [W/(m²K)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.227</td>
</tr>
<tr>
<td>II</td>
<td>0.224</td>
</tr>
<tr>
<td>III</td>
<td>0.218</td>
</tr>
<tr>
<td>Mean value</td>
<td>0.223</td>
</tr>
</tbody>
</table>

U-value tin-mortar 0.14 W/m²K
U-value new earthship house 0.08 W/m²K

THE FIRST PASSIVE HOUSE IN MACEDONIA – BUILDING OF “EKSPRO COMPANY”

First building in Macedonia that spends less than 10 kWh/m²a, designed and built according to high technical requirements and standards for EE: shape, orientation, thermal insulation, amount of openings and other glass parts ensuring minimal loss of energy and gains in summer, geo-thermal pumps, under floor heating, Trombe wall, heat recovery ventilation etc. This building promptly returns funds invested in construction; savings are 16€ per day in comparison with a house with an ordinary insulation.
Challenges of Buildings Modernization
Assessing the Social and Economic Aspects: Experience of Lithuania

Jolanta Šadauskiienė, Lina Šeduikytė, Vytautas Stankevičius, Jūratė Karbasaitė, Romalda Morkvičienė

Faculty of Civil Engineering and Architecture, Kaunas University of Technology, Studentu str. 48, LT-51367, Kaunas, Lithuania

ABSTRACT
Energy saving has become one of the foremost priorities in the European Union and a great deal of attention is directed towards the sector of sustainable building. However, the EU members that have an extensive Soviet heritage now face a great difficulty in reducing energy consumption. Since many apartment buildings are in especially poor thermal condition, and the heat supply infrastructure is normally and physically outdated, energy consumption for heating is significant. This project is important for the region as it analyses financial and social criteria of building modernization and proposes a new model for its financing on the basis of the calculation of energy input per one degree-day of the building.

METHODOLOGY
Climate data. The registered day temperatures during the heating seasons of the period 1996-2010 were analyzed and their mean values for each heating season were determined. As the reliability of energy consumption estimation in buildings is very important to the assessment of economic efficiency of modernization, the value of degree-days was used as the base parameter for climate data for calculation of energy consumption. The mean value of the degree-days is 3789 for the city of Kaunas, Lithuania.

Investment model is based on the investments of a specific municipal or independent enterprise which invests into the apartment building modernization. The energy consumption in the building after modernization is estimated as the registered energy consumption for building heating as in degree-days of the considered period. Wh/(K·m2) for 1 m2 of heated area. An apartment owner should pay for the modernized energy amount according to the conditions before the modernization. Such payment order will be kept until the investments will be fully covered. Fig. 2 gives the implementation scheme of the suggested method.

Investigated building was typical five storey apartment building built in 1976 and containing 100 apartments with the total heated areas of 4418 m². The total initial investment of the building was estimated to reach 451.8 mln. Eur and the planned energy savings amounted to approximately 40%. The actual total sum of the investments was 2048.7 mln. Eur.

Investigated building was a five storey apartment building built in 1976 and containing 100 apartments with the total heated areas of 4418 m². The total initial investment of the building was estimated to reach 451.8 mln. Eur and the planned energy savings amounted to approximately 40%. The actual total sum of the investments was 2048.7 mln. Eur.

RESULTS
The estimation of energy consumption efficiency with the application of degree-days is meaningful in all Europe. In different countries, the energy consumption is unequal as it depends on the outdoor climate characteristics and thermal insulation of buildings. During the cold period, energy demand for heating makes up the greater part of the whole energy consumption in the Nordic countries, whereas in the Southern countries the energy is consumed mostly for air cooling and air conditioning.

The monitoring results of the energy consumption for heating of the considered apartment building before and after modernization are presented in Fig. 3 and Table 2.

Table 2. Results of modernization and progress of investment pay-back for apartment building

<table>
<thead>
<tr>
<th>Year</th>
<th>Start</th>
<th>Progress</th>
<th>Remainder of investments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>10.4</td>
<td>16.42</td>
<td>22.84</td>
</tr>
<tr>
<td>2009</td>
<td>11.9</td>
<td>18.53</td>
<td>25.41</td>
</tr>
<tr>
<td>2010</td>
<td>12.5</td>
<td>20.57</td>
<td>30.07</td>
</tr>
<tr>
<td>2011</td>
<td>13.5</td>
<td>22.57</td>
<td>36.07</td>
</tr>
</tbody>
</table>

Investigation was carried out for apartment building before and after modernization.

CONCLUSIONS
The project suggests a new model of investments and modernization of apartment buildings for the Lithuanian conditions. The apartment owners would provide payments according to the recent energy consumption level till the end of the pay-back period (12-25 years), and in turn, the payment would be divided into a real payment to the energy supplier and return of investments. The state would support a successful implementation of the modernization projects.

Special institutions at municipalities were established with the purpose to be involved into the implementation of the modernization projects, so local authorities would gain the greatest part of the modernization benefits.

The presented calculation model evaluating degree-days enables the calculation and inter-comparison of data gathered in all European Union member states without taking into account specific climate parameters of each.

REFERENCES


Scenarios for and a Roadmap towards the Smart Energy Region Zurich 2050

Harry Spiess, Zach Burgess, Vicente Carabias, Brandon Malofsky, Luke Habib, Tobias Kuehn,
Sam Khalandovsky, Theo Weiss

*ZHAW Zurich University of Applied Sciences, Institute of Sustainable Development, Switzerland

WPI Worcester Polytechnic Institute WPI, Boston, US

Methodology of the Scenario Development Process

The Swiss energy transition (“Energiewende”) is a challenge. To handle this, scenarios are a possible tool for policymakers to lead the development in a desirable direction. Therefore scenarios with the target of a low carbon zero nuclear power future and smart energy region in 2050 were developed for the Zurich region. The work is part of COST Action TU1104 Smart Energy Regions. The results enable a transfer to other future smart energy regions.

The scenario-development was based on workshops with experts from energy utilities, the district administration, re-presented by the department energy, environment and local promotion and universities with their expertise in technology, economy and energy efficiency. The scenario process was based on the formative scenario analysis method (Scholz & Tiije, 2002).

The important impact variables for the scenario process cover several technological aspects, such as synergies of operational systems, decentralization of renewable energy production, grid conversion, maintaining energy security, contribution to economic prosperity and to quality of life. “Smart Growth” was chosen by the experts as the most desirable scenario for a smart energy region Zurich 2050.

The roadmap integrates technological possibilities combined with purposeful political decisions at the appropriate time slots in a schedule towards 2050.

With the participation of students from the ZHAW School of Engineering and the Worcester Polytechnic Institute WPI, Boston, it was possible to enrich the workshops with the opinion of future generations, with the knowledge of upcoming smart energy technologies and with a global perspective.

Roadmap recommendations:
The roadmap shows several boxes with varying colours. The boxes that share the same colour indicate that they have a relationship with one another.

* The main goal or recommendation for those coloured boxes.

Acknowledgements:
This work resulted thanks to the experts’ participation and the research project C13.0147 Towards Smart Energy Regions funded by the Swiss State Secretariat for Education, Research and Innovation (SERI).

Lead author’s e-mail address: sphi@zhaw.ch


Roadmap towards the Smart Energy Region Zurich 2050