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Spatial Data for Modelling Building Stock Energy Needs

Annex to the Proceedings of the Workshop

Participants' contributions

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The role of INSPIRE in the EULF Energy Pilot

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Introduction

This paper, prepared for the workshop "Spatial data for modelling building stock energy needs", focuses on the role of INSPIRE in the EULF Energy Pilot. It has been prepared in the form of questions and answers, in order to facilitate the discussions that will take place during the workshop with the invited experts. Some of the questions are still not answered, waiting to collect feedback during the workshop.

What is INSPIRE?

INSPIRE is the acronym of the Directive 2007/2/EC of the European Parliament and of the Council entered into force on the of May 15th 2007, establishing an Infrastructure for Spatial Information in the European Community.

INSPIRE aims to support EU environmental policies, and policies or activities which may have an impact on the environment. It defines binding Implementing Rules (Commission Regulations) and non-binding Technical Guidelines for the interchange of spatial data through interoperable data models and services.

INSPIRE is based on the infrastructures for spatial information established and operated by the 28 Member States of the European Union and it addresses 34 spatial data themes[1].

What is EULF?

EULF is the acronym of European Union Location Framework[2], which is a project led by the Joint Research Centre of the European Commission and is part of the Interoperability Solutions for Public Administrations (ISA) Programme[3], run by DG Informatics (DIGIT). The EULF is a framework of recommendations, guidance and actions to improve the way location information is used in all public services across Europe, targeting benefits for businesses, citizens and government in key areas of EU activity, such as Transport, Marine and Energy policy. The EULF builds on the spatial data infrastructure for Europe being implemented by INSPIRE.

What is EULF Energy Pilot?

The Energy Pilot is one of the three pilots (the other two dealing with Transport and Marine sectors, respectively) to test the concept of the EULF. It started in the last quarter of 2015, based on the outcomes of a "pre-pilot" feasibility study which are documented in the "Location data for energy

[1] http://inspire.ec.europa.eu/index.cfm/pageid/2/list/7

[2] Information about the EULF, including links to publications and key events, can be found at http://ec.europa.eu/isa/actions/02-interoperability-architecture/2-13action_en.htm

[3] Information about ISA is available at http://ec.europa.eu/isa/ and at http://ec.europa.eu/isa/library/isa-work-programme/index_en.htm

efficiency policies" JRC Technical Report[4]. The feasibility study aimed to verify the potential for an effective application of spatial data to support the monitoring requirements of the different EU energy efficiency policies and initiatives, which include data from different sources and at different scales (building, district and national).

Q.1

At what extent can INSPIRE fill-in the data gap highlighted in the JRC Technical Report of the Energy Pilot Feasibility Study? Which kind of data potentially relevant for the Energy Pilot will be made available by INSPIRE and when?

A.1

It is important to focus on two aspects related to INSPIRE in the context of the Energy Pilot, in order to do not overemphasize INSPIRE expectations and benefits which are still not easily measurable, but at the same time to highlight the potentialities of current and future INSPIRE implementations in the Member States:

- fit for purpose of INSPIRE harmonized datasets with the Energy Pilot scope and objectives;
- timing of availability of INSPIRE harmonized datasets.

<u>Fit for purpose aspect</u>

In the above mentioned JRC Technical Report a number of candidate INSPIRE data themes have been identified as fitting for purpose with the data flows to be analysed/implemented in the Pilot itself, namely Buildings, Addresses, Cadastral parcels, Utility and governmental services, Production and industrial facilities, Energy resources, Atmospheric conditions, Land Cover, Statistical Units, Population Distribution.

The most relevant INSPIRE data theme is undoubtedly Buildings (BU), but some of the attributes of the its data model that are relevant for the Energy Pilot scope and objectives have the following characteristics:

- they are "voidable"[5] and/or optional in the binding-by-law BU core data model (e.g. dateOfConstruction and currentUse in *Figure 1*);
- they are voidable and/or optional in the draft BU extended data model (e.g. energyPerformance, heatingSource, heatingSystem, materialOfFacade, materialOfRoof, materialOfStructure in *Figure 2*).

Therefore, it can't be expected that all data providers will deliver datasets containing this information.

[4] http://publications.jrc.ec.europa.eu/repository/handle/JRC96946

[5] The «voidable» stereotype is used to characterise those properties of a spatial object that may not be present in some spatial data sets, even though they may be present or applicable in the real world.

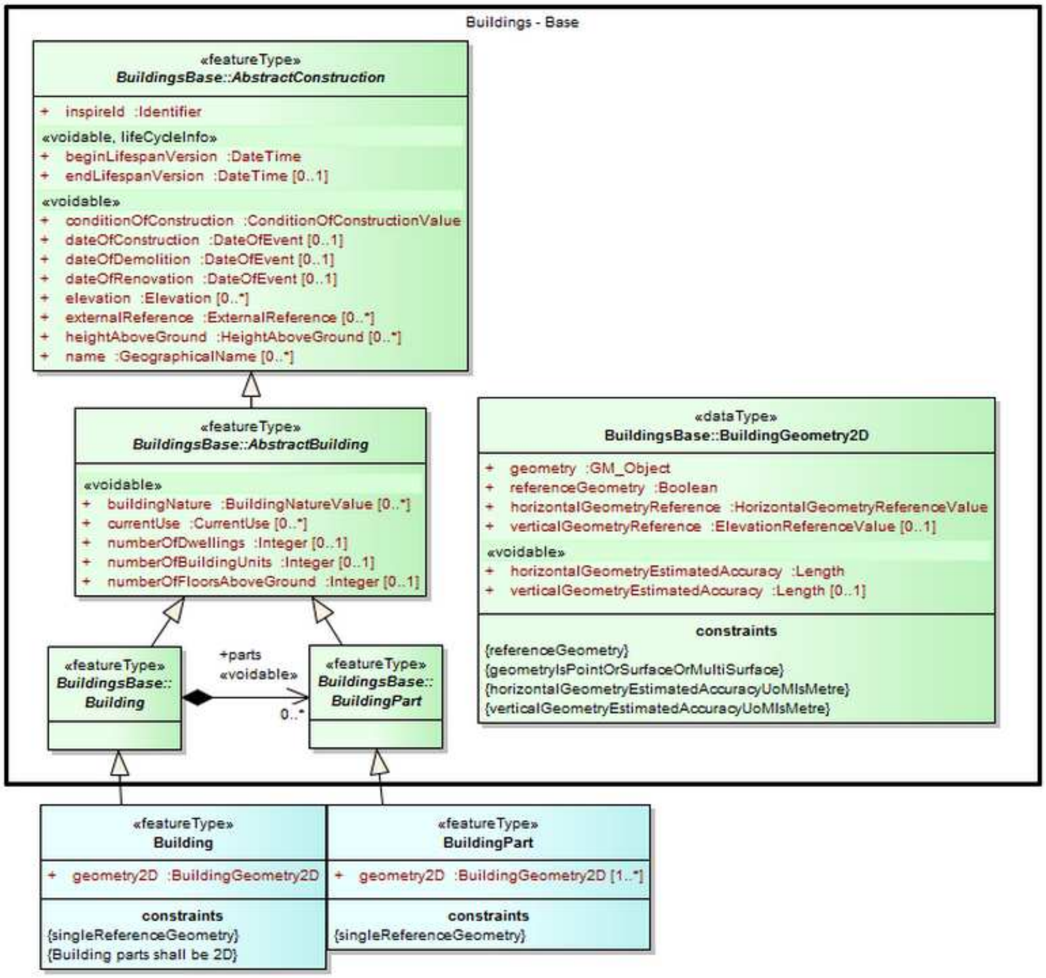

Figure 1: BU Core 2D data model

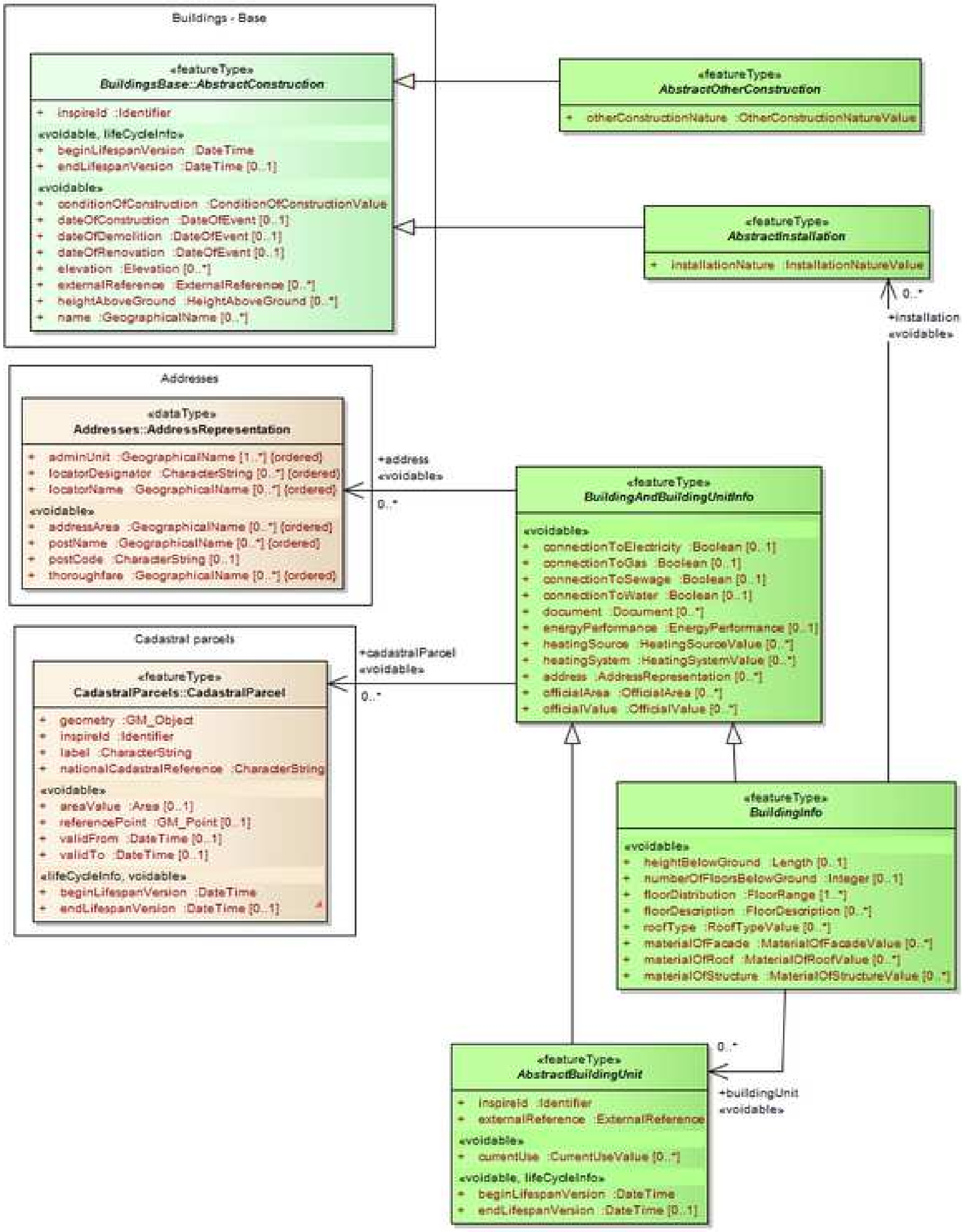

Figure 2: BU Extended Base data model

An initial mapping exercise has been carried out (in the Feasiblity Study and documented in the Technical Report) between the building related elements of the data models required by EPBD[6] and

[6] Energy Performance of Buildings Directive - http://eur-lex.europa.eu/legal-content/EN/ALL/;ELX_SESSIONID=FZMjThLLzfxmmMCQGp2Y1s2d3TjwtD8QS3pqdkhXZbwqGwlgY9KN!2064651424?uri=CELEX:32010L0031

the corresponding elements present in the INSPIRE data specification on Buildings[7]. The main outcome of this mapping exercise is that the building-related data models required by EPBD and CoM[8] are semantically richer than the data models under INSPIRE. For instance, *Figure 3* shows the UML representation of the element of the INSPIRE Buildings Base Extended data model (Feature Type BuildingAndBuildingUnitInfo) which deals with energy related aspects.

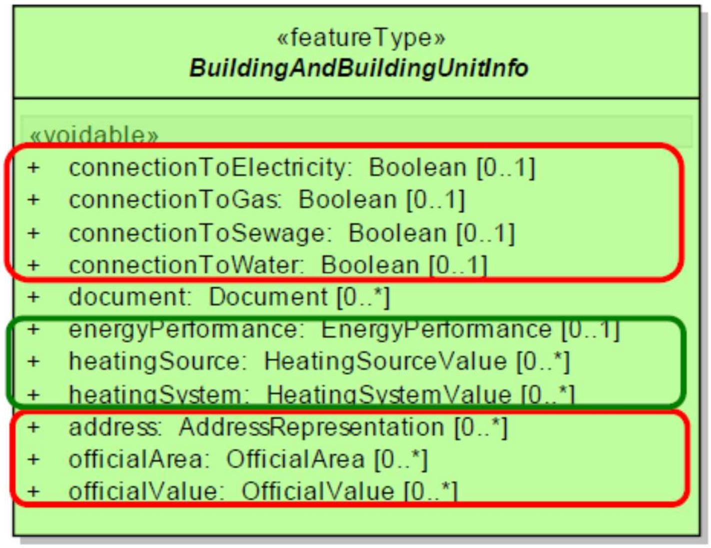

Figure 3: INSPIRE Feature Type BuildingAndBuildingUnitInfo

From this figure it is evident that:

- there are 4 boolean attributes which can be used just to store the information if the building (or building unit) is connected or not to the different networks (electricity, gas, sewage, water)[9];
- there is one attribute (energyPerformance) which can be used to store the information related to the energy label;
- there is one attribute (heatingSource) which can be used to store the information related to the source of energy used for heating (i.e. electricity, naturalGas, etc.);
- there is one attribute (heatingSystem) which can be used to store the information related to the system of heating (i.e. stove, central heating, heat pump, etc.).

Conversely, there are additional attributes required by the EN 15603 standard (which the EPBD data modelling requirements are based on), like "Energy need" for heating, cooling, ventilation, air conditioning, domestic hot water, lighting, appliances, which do not match with any attribute existing in the current INSPIRE data model for buildings.

In general, because not all the elements of the data models required by EPBD and CoM have a corresponding element in the relevant INSPIRE data model, these elements with a missing correspondence with INSPIRE need to be further analysed in order to proper address an extension of

[7] http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_BU_v3.0.pdf
[8] Covenant of Mayors – http://www.covenantofmayors.eu/
[9] It is worth noting the absence of a similar boolean attribute to identify buildings connected to district heating network

the existing relevant INSPIRE data models. It is also worth highlighting that the extension of an existing INSPIRE data model is subject to precise rules and conditions, set to ensure that it does not break the interoperability of harmonised data and services[10].

Citygml Energy ADE[11] initiative and GeoSmartCity[12] project are producing results whose reuse in the Energy Pilot is encouraged/recommended.

Timing

According to the INSPIRE Implementation Roadmap shown in *Figure 4*, INSPIRE conformant datasets which are newly collected or heavily restructured will have to be available by October 21st 2015, whilst all BU datasets (i.e. also the existing datasets to be transformed) will have to be available by October 21st 2020.

Therefore, because most of the BU related datasets to be made conformant to INSPIRE are existing, and consequently fall in the second deadline, only few INSPIRE conformant BU datasets are expected to be available before 2020 (mainly those coming from pilot projects/initiatives).

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[10] INSPIRE Generic Conceptual Model - http://inspire.ec.europa.eu/documents/Data_Specifications/D2.5_v3.4.pdf

[11] http://en.wiki.energy.sig3d.org/index.php/Main_Page

[12] https://themes.jrc.ec.europa.eu/discussion/view/61352/extended-bu-data-model-for-energy-efficiency

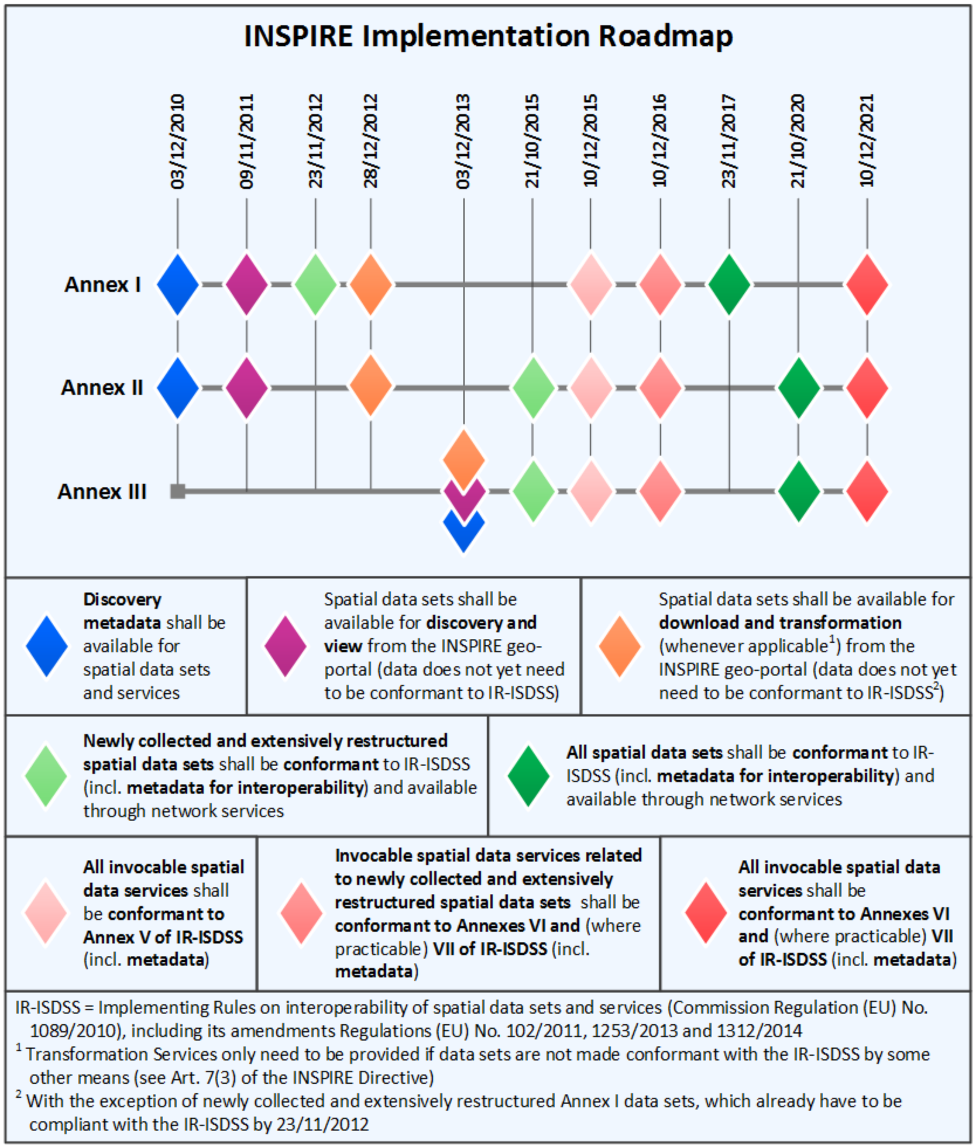

Figure 4: INSPIRE Implementation Roadmap

Despite the two aspects above described highlight that INSPIRE benefits supporting the Energy Efficiency policies lifecycle are not yet tangible, it's important to highlight the potentialities of current and future INSPIRE implementations in the Member States, assuming that some recommendations are followed.

Q.2

Is it possible to formulate recommendations to better address, in general, on-going and future INSPIRE implementations potentially useful to support Energy Efficiency policies lifecycle?

A.2

Yes. A first draft list of recommendations is provided below:

- to properly extend existing INSPIRE BU data models in order to take into account the data modelling requirements coming from Energy Efficiency policies, considering both existing similar activities (e.g. citygml Energy ADE initiative and GeoSmartCity project) and the rules for INSPIRE Data Specifications extension[13];
- to use these extended data models as target data models in as many as possible data harmonization processes related to Energy Efficiency policies, in order to improve data interoperability at EU level;
- to carefully compile relevant metadata elements, such as lineage and resource locator, in order to document and share relevant data processing activities and therefore facilitate their reuse.

Q.3

Are 3D data of buildings really needed or the semantic enrichment of 2D data models will be sufficient to satisfy the data modelling requirements contained in the Energy Efficiency policies?

A.3

A detailed cost-benefits analysis should be made.

Q.4

Is it worth to design a common data model to harmonise the collection of data coming from heterogeneous devices providing energy consumption dynamic measurements?

Q.5

How to overcome the barrier related to the non-disclosure of energy consumption data classified as commercial sensitive by Utility Companies?

Q.6

At what extent the use of INSPIRE can be beneficial to implement the data-flows relevant to the

[13] INSPIRE Generic Conceptual Model - http://inspire.ec.europa.eu/documents/Data_Specifications/D2.5_v3.4.pdf

data Energy Efficiency policies lifecycle?

A.6

Possible alternative scenarios are shown in the *Figure 5*, in which the following acronyms are used:

BU = Buildings

EP = Energy Performance

BEI = Baseline Emission Inventory

NEEAP = National Energy Efficiency Action Plan

A draft list of possible alternative scenarios depending on different combinations of data-flows is provided below:

1. A vs. B (where A = A1+A2+A3)
2. D vs. (A+F)
3. (A+F) vs. (A1+A2+A4)
4. E vs. C (where C=C1+C2+C3)
5. I vs. (C1+C2+C4)
6. J vs. (A+G)
7. (C+H) vs. (C1+C2+C4)

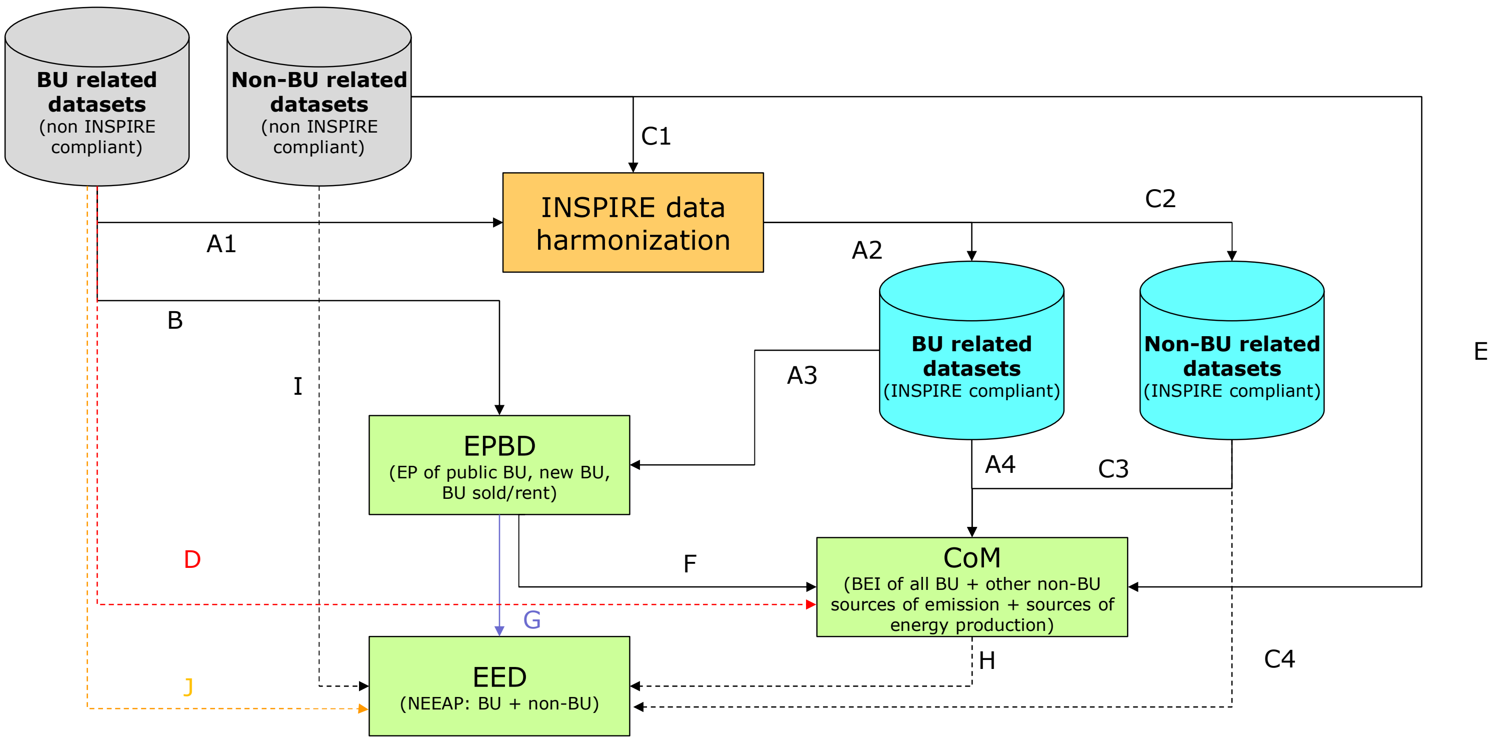

Figure 5: Possible alternative scenarios to implement data-flows relevant to the data Energy Efficiency policies lifecycle

Workshop: **Spatial data for modelling building stock energy needs, JRC Ispra**

Contributed text: **A win-win strategic approach in support of energy-related spatial data collection**

Contributor: **Alexander Deliyannis, Sympraxis Team**

INTRODUCTION

The JRC Feasibility Study "Location data for buildings related energy efficiency policies", undertaken under the European Union Location Framework (EULF) Project, concludes, among others, that

— *it is possible to apply a generalised methodology to support different energy efficiency policies using location data as an integrating factor and combining both real and extrapolated data to indicate progress in meeting efficiency targets and help in planning relevant actions;*
— *geospatial technologies in general and accurate location data in particular can play an important role in the energy efficiency field, significantly increasing:*
    - *the efficiency of data collection, elaboration and communication processes in all phases of the life cycle of energy efficiency policies;*
    - *the effectiveness of decisions taken by different stakeholders (policy-makers, technicians, citizens)*

The Study proposes a methodological approach, hierarchically structured with relevant data collection levels

— **Building level**: Energy Performance of Buildings
— **District level**: Energy Efficiency Directive
— **Urban level**: Covenant of Mayors
— **National level**: Energy Efficiency Directive

and a corresponding Conceptual Architecture to support the methodology.

The present contribution focuses on a complementary approach supporting the proposed methodology, by suggesting additional incentives for data collection at the various levels.

Furthermore, brief reference is made to two other complementary approaches, namely:

— Integrating iterative processes at the various levels, allowing for the use of mixed data (measured, calculated, default values or estimates) and the gradual improvement of data quality and precision as the systems are utilised.
— A possible role for big data techniques to compensate for the lack of available data in certain cases, as well as to recognise patterns of energy consumption and savings potential.

THE 'WHYs' and 'WHOs' OF BUILDING ENERGY DATA COLLECTION

Motivations and structures for data gathering may differ significantly at the various locational levels, i.e. building / district / urban / national. The following paragraphs look at the various levels and potential corresponding key actors. The latter may differ from the main actors identified in the Feasibility Study; in such cases the intention is to highlight the potential for, among others:

- alternative **sources of data**;
- **stakeholders 'lobbying' the actors** identified in the Feasibility Study, in order to collect and provide the relevant data.

Building level: citizens / consumers / building managers, owners and tenants

Citizens / consumers / building managers, owners and tenants may have several motives and opportunities to provide building energy data. Examples include the issuance of Energy Performance Certificates (EPCs) for buildings or dwellings, and private initiatives to reduce financial costs by improving their homes' energy performance. In practice, these two activities are often combined, with the EPC being accompanied by customisable suggestions for energy improvements.

A multitude of tools are available nationally or EU-wide to facilitate such activities. Many of these are desktop applications, but web-based tools, such as the Greek easykenak (www.easykenak.gr) are of particular interest. Similarly, the UK Energy Saving Trust's Home Energy Check (http://hec.est.org.uk/) provides users with a report on their home's energy use and the savings that are possible by following specific steps, such as improving the insulation and installing new heating equipment.

The use of online tools for EPC calculation, combined with related activities such as inspections, allows the gradual aggregation of relevant building stock data into centralised databases. The German CO2-online heating atlas (www.buildup.eu/tools/8972) illustrates the possibilities: it aggregates data from 50.000 buildings, presents it in a graphical interface, and allows users to access data from selected federal states and regions. It is worth noting that CO2-online has data on one million buildings, but has only published the data for which it was explicitly granted the right by owners/tenants.

Another approach encouraging voluntary data contribution by users is demonstrated by the social/gamified Social Electricity application (www.social-electricity.com) available for the EU and Singapore. This uses social networks and gamification to encourage energy information sharing and improvements. Similar applications have been developed by national energy agencies in various Member States, e.g. ControlaEnergia (http://app.energythatmatters.info) allows users to register their gas and electricity consumption and receive personalised energy advice, as well as comparison with their past consumption and that of other users under similar conditions.

All of these tools empower the end users and building occupants who constitute the 'managers' for the majority of residential buildings. Similar tools are available for non-residential buildings, e.g. NL Agency's Energy Explorer Utility (www.buildup.eu/tools/28424) which focuses on refurbishment and covers non-residential buildings, including offices, warehouses and various shops. Correspondingly, offering such tools to users can open a gateway for aggregation of real building energy data. This is particularly powerful where the collection itself is automated, i.e. via a Building Energy Management System; see the example of Intelen further below.

Several other building energy-related data tools available to the various locational levels are presented in the BUILD UP overview article “Data tools supporting improved energy performance of buildings: Evolution and perspectives” (pt.1 www.buildup.eu/news/45030, pt.2 www.buildup.eu/news/45869)

Intermediate level: Neighbourhoods

Neighbourhoods have not been included in the Feasibility Study as a separate level, yet they represent a significant potential for synergistic energy-related improvements whose benefits can be immediately apparent to citizens. As such, neighbourhoods can provide strong incentives for energy data contribution to central databases.

Neighbourhood energy data can be aggregated through tools aimed for buildings and support energy planning at a level where joint procurement can be implemented with major benefits. A case in point is the initiative for Energy Positive Neighbourhoods explored by the FP7 IDEAS project. A recent BUILD UP webinar (www.buildup.eu/news/46501) explains the concept and potential.

There is also a benefit in adding a level of data input (and complexity) in respect to centralised databases: information granularity. As noted in the Feasibility Study, “EED reporting 'Districts' are not related to standard administrative units (NUTS)”. Neighbourhood-level data can help compensate for this disharmony.

District level: local councils

Local councils and other local (sub-municipal) formal or informal administration structures, including among others local citizens' associations, can play a significant role in energy data collection. Their practical incentive: the resolution of energy-related local issues at their own level.

Here again, tools such as those described above are readily available and can easily be used, e.g. to share and compare energy data between dwellings, buildings and building units in the same area, leading to valuable insights on potential improvements. Most importantly, such improvements may include district-level initiatives, including the management of open spaces, tree coverage, cool materials, traffic, and even district heating and cooling, etc.

Urban level: Municipalities and regions

At the urban level, cross-correlation of energy and (external) conditions data among similar districts can support the establishment of relevant benchmarks, highlighting potential issues as well as the potential urban-level solutions.

A case in point is the mapping of urban heat islands, which constitute an energy intensity vicious circle, i.e.: the heat island undermines the efficiency of air conditioning systems, systems are required to operate at higher intensities, in turn further contributing to the heat island effect outside of buildings. Targeted municipal/regional action such as cool materials, cool roofs, increased tree coverage and traffic management can significantly reduce energy consumption and improve citizens' well-being.

National level: Member States

The Member State represents the higher direct interest level where collected data can readily be used to support decision making and interventions leading to higher energy efficiency. The potential has been extensively explored, among others, by the Concerted Action EPBD.

Catalysts: corporations and SMEs

Operational collection of data at the distinct levels can be supported to a great extent by commercial offerings, directly delivering the benefits back to consumers, local administrations etc. Energy retailers constitute the most evident player in this regard, but a much broader range of energy data inputs can be exploited with the contribution of other companies, including SMEs, focused on more specific markets.

Intelen's DiG platform (http://intelen.com/us/solutions/dig.html) is an example of a local/central approach exploiting this potential: it allows energy users to monitor their own consumption –in full detail if they have installed smart plugs– and energy utilities to gain insights into their clients' consumption patterns.

POTENTIAL ALLIES

The following organisations and initiatives are noted for possible consideration within the context of the pilot implementation, as well as the long term promotion of the collection and processing of INSPIRE-compliant energy-related locational data.

European Environment Agency (EEA)

In respect to the overall EULF approach, an organisation with substantial experience in integrating (location and non-location) data is the European Environment Agency (www.eea.europa.eu/data-and-maps). Such experience ranges from integrated pan-European work such as the monitoring of bathing water quality, to voluntary citizen-science initiatives such as LitterWatch.

Concerted Action EPBD (CA EPBD) and Concerted Action EED (CA EED)

The Concerted Actions for the EPBD and EED bring together the national focal organisations responsible for the respective directions and can provide valuable fora for the promotion of the EULF priorities and good practices.

COMPLEMENTARY SUGGESTIONS

Iterative approach

It is quite reasonable to assume that 'data gaps' will be found in the implementation of various steps/stages of the location data methodology, possibly already during the pilot phase, but most probably within the context of wider applications. It is proposed to adopt a flexible approach, whereby mixed data (measured, calculated, default values or estimates) may be used, with non-measured values compensating for the lack of measured data, at least temporarily. Results can then support, among others, iterative applications (e.g. modelling), whereby newly measured data can then be used to improve the accuracy of further estimations.

A role for big data

So-called 'big data' techniques have recently uncovered interesting correlations between seemingly unrelated data, which can support useful estimation of missing parameters. A popularised example is the prediction of income level from Twitter postings (www.upenn.edu/pennnews/twitter-behavior-can-predict-users-income-level); similar work exists for location data, and could be applied for energy-related parameters.

Data availability on energy consumption in buildings

Overcoming gaps for the European Building Observatory

November 2015

Buildings Performance Institute Europe
Maarten De Groote
Francesco Mariottini
Aleksandra Arcipowska

TABLE OF CONTENTS

•

1 INTRODUCTION ON THE BUILDING OBSERVATORY

The Building Performance Institute Europe coordinates the development of the “Observatory of the EU Building Stock” and related key policies, contracted by the European Commission. Other consortium partners are the Energy Research Centre of the Netherlands, Ecofys, ENERDATA and SEVEn. In addition, there are 18 subcontractors in the project representing all 28 EU MS.

The objective of the assignment is to set the methodology for the EU Building Stock Observatory and to gather good quality data on energy efficiency of the building stock across EU-28.. The work involves consultation with Member States’ authorities and agencies responsible for the building sector, including the statistics offices in charge of collecting data from the national building stock.

The template for data collection consists of about 250 indicators. The list of key indicators for the Observatory, based on a clearly defined methodology, includes (and is not limited to) the following areas:

- Characteristics of the building stock and energy consumption (e.g. floor area, number of buildings per type, use, age,etc.).
- Characterisation of buildings’ energy performance (e.g. U-values, , technical building systems, etc.).
- Certification (e.g. number of energy certified buildings, other certification schemes, etc.) .
- Financing (e.g. level of investment associated with deep retrofits and with major renovation, financial schemes targeting deep renovation, etc.).
- Social issues and fuel poverty

The public domain of the EU Building Observatory, will be launched at the beginning of 2016. It will provide a comprehensive knowledge resource for policy makers, investors, industry stakeholders, energy utilities, local and national authorities and researchers to underpin decision making, financial and long-term strategic support.

The Building Stock Observatory will support monitoring of the EPBD implementation, as well of relevant articles of the EED (such as art. 4 and 5) and of the RED (such as art. 13 and 14) at national and regional levels.

2 DATA COLLECTION METHODOLOGY

In the scope of the project, the list of the indictors (i.e. definitions and data needs) has been proposed, discussed with various stakeholders and finally agreed with the European Commission.

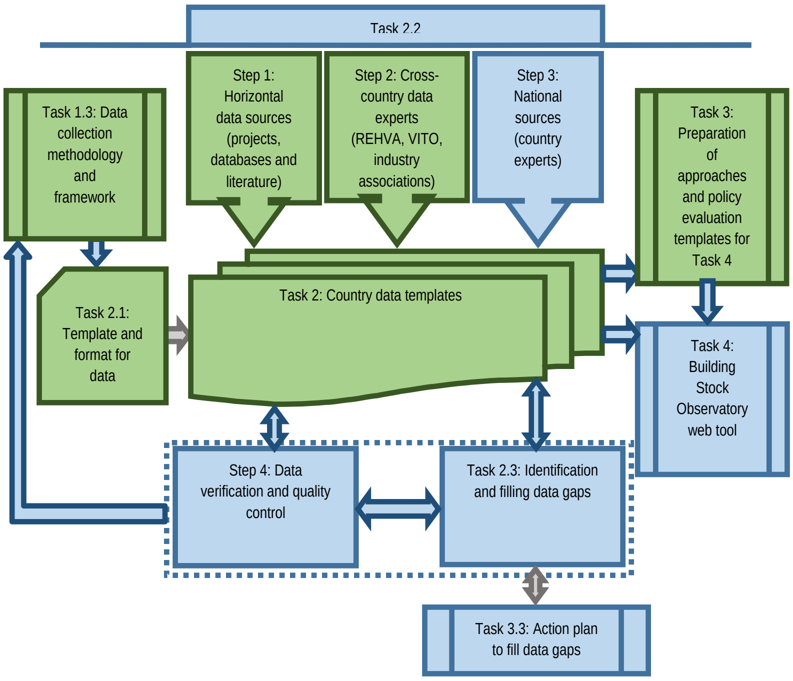

Figure 1 - Methodology of data collection.

Following the project methodology, the data-collection process is conducted in four phases:

- **STEP 1: Data collection for indicators based on horizontal sources**. The consortium focused on:
    - **Existing horizontal sources with EU coverage.** These are sources like Eurostat, IEA, Odyssee-Mure, Entranze, Episcope, iServe, BPIE Data Hub, EU Comm's Market Observatory and others.
    - **Existing literature, projects and periodic reporting of the EU Member States (MS)** such as CA-EPBD reports, studies, EUR'Observer periodic reports, NEEAPs, NREAPs, reporting under the EED, Ecodesign preparatory studies, EU Commission initiatives and portals such as RES-Legal, etc.
- **STEP 2: Cross-country data provided by experts and stakeholders** The two main subcontractors of the project, i.e. REHVA and VITO, have filled in cross-country EU data regarding HVAC equipment, lighting, renewable energy sources and indoor air quality.

  In addition, 15 stakeholders active in the field of energy efficiency in the built environment have been contacted.
- **STEP 3: Data collection based on national data sources.** There are 18 subcontractors in the project, whose role is to provide data available from the national sources.
- **STEP 4: Data verification, quality control and selection of data.** Data sets will be rejected if the reliability verification does not provide satisfying outcomes.

3 RESULTS OF DATA AVAILABILITY EXERCISE

Prior to data collection process, the consortium conducted an in-depth analysis of data availability both on national and European level. The results of the data availability for the indicators related to building energy performance (only) are the presented as follows:

Building stock characteristics. While data on building stock characteristics are relatively easy traceable (e.g. IEE ODYSSEE-MURE project, BPIE Data Hub, INSPIRE project), data for indicators on (energy) renovation are the most challenging to collect mainly because of lack of harmonisation on the definitions. Some information is provided by IEE EU projects such as ZEBRA2020 and EPISCOPE.

Energy consumption. Data coverage on total final energy consumption is rather good although less information is available for non-residential buildings. The new initiative by Eurostat (Commission Regulation No 431/2014), will provide in the future a good source of data on energy consumption in the residential sectors; data for some countries is already available in the source.

Technical data on energy performance, disaggregated into building envelope, on-site renewable energy generation, technical systems and embodied energy:

- **Building envelope.** In majority of MS, there are no official statistics on U-values; some data is available from European (e.g. ENTRANZE and INSPIRE projects) or national sources. Gaps concern also airtightness.
- **On-site renewable energy generation.** Data of biomass and heat pumps is to some extend available and collected annually by Eurostat and EurObser'ER database, while information on PV is only available on national level and is not specified into residential and non-residential installations.
- **Technical systems – Space heating.** There are large gaps on this indicator and information on average efficiency and age of systems is difficult to obtain. High-level data is only available in some countries (provided by ENTRANZE and TABULA projects). In order to fill the identified gaps contacts with industry (associations) are being set up. Stakeholder, such as REHVA EHI, EHPA are supporting data collection for the technical systems;
- **Technical systems – Space cooling.** There is little data to be found on space cooling.
- **Technical systems – Domestic Hot water.** Compared to data on space heating and cooling, horizontal data on domestic hot water is more scarce. However, on national level about half of the countries have data on the number of building (units) with boilers.
- **Technical systems – Ventilation.** For data on Ventilation, the preparatory studies for Lot 10 of the Ecodesign can be consulted. On the national level, data on ventilation is not often available.
- **Technical systems – Lighting.** Data on lighting is available in the Melisa database, developed by Van Holsteijn & Kemna on EU level.
- **Technical systems – Cooking and electric appliances.** Horizontal data for Cooking Appliances is not easily available; Data on appliances are available in most of the countries in the ODYSSEE- MURE database.
- **Technical systems – Metering.** There is little data to be found on metering systems
- **Embodied energy.** Embodied energy is a topic for which hardly any monitoring is done and it is unlikely that empirical datasets can be found on this topic.

Certification – Distribution of EPCs. National and regional EPC databases are the most important source of data on the EPC distribution, and some of them have been analysed within ZEBRA2020 project. Regarding quality and compliances of EPC schemes, important sources are Concerted Action EPBD, the national reports on Energy Performance Certificates and the inspections of heating and air conditioning systems (requested by the European Commission).

The results of the data availability for the indicators related to building energy performance are presented in the annex.

4 The importance of data collection: BPIE response to the EPBD survey

The availability and reliability of the building data vary across Member States; data collected by the Eurostat in this regards are rather limited.

As stated in the previous chapter, many gaps have been identified during the data collection process of the “EU Buildings Stock Observatory project”. Thus, the potential to change and improve the status quo relies also on the launching of the mandatory data collection on energy consumption in housing sector by Eurostat and additional targeted European and national policies.

There is a need to consistently improve the enforcement of the EPBD provisions in Member States and strengthen the monitoring of the compliance both at Member State and European levels. For instance, only 50% of the MS have a view on the compliance rates of new buildings with energy performance requirements, which is highly problematic. It is a major barrier for policy making (on European, National and Regional level) and it is harmful for the credibility to citizens.

The European Commission organised a public consultation on the EPB directive, running from June till October 2015. The public consultation launched the review into the directive, which is due by the end of 2016 as required under article 19 of the directive. The online survey consists of 79 questions, covering various topics (such as renovation existing buildings, smart buildings, energy poverty, etc.). BPIE responded to this questions and emphasized in some answers the need for public and harmonised data availability to support European, National and local policy making.

Need for harmonised methodologies

The findings of the EPISCOPE project highlight a strong need for better harmonisation of national and official statistics related to building performance. While some types of data (i.e. surface) are easier to harmonise, public information on systems and technologies are usually too peculiar and country specific.

EPCs require a number of input data that depend on the application (e.g. residential versus non- residential, new versus existing building) and on the country or region[1]. This is also due to the fact that the majority of Member States use their own energy performance calculation methodologies and not the available CEN standard.

There is a need to secure sufficient resources (i.e. financial & human) for the data collection, verification and quality control, both on the European and national level. European Commission should provide guidance for the Member States in regards of the type and format of the data for monitoring of the improvement of the energy efficient in buildings, including non-residential sector. The links between EPBD and CEN standardisation should also be further strengthen.

More convergence on methodologies and targets would trigger more innovation in the field and support a technology leadership of Europe in the field.

Monitoring of building renovations

To date, information on the type and level of the renovation activities is very limited. A valuable learning in this regards could be taken from the ongoing EU projects, such as EPISCOPE, Renovalue etc., or national initiatives, such as the English Housing Survey. Adequate monitoring measures need to be applied on the EU and MS level, especially in case of public financing (including Cohesion Funds).

[1] Even within the same country (e.g. Italy, Austria and Belgium), different approaches are observed.

Serious consideration should be given to oblige MS the obligation to report on renovation market activity in their NEEAPs.
In addition there is the need for stricter and more harmonised definitions on the rate and depth of renovation (i.e. deep renovation, light renovation, rate of renovation and more). A distinction needs to be made between general renovation for aesthetic purposes and energy related renovations, since the first does not necessarily contribute towards the aims of the EPBD and has the potential to distort the reality of reported progress.

Enforcement of EPC databases

EPC databases are the central source of information on the energy performance of the EU building stock. Unfortunately, some MS don't have a central database and in case they do, databases are mostly not public accessible.
The EC should impose the Member States to gather all information on EPCs in national databases, with the purpose of ensuring monitoring and compliance, and make (a selection) of data available on a central EU database. Therefore, there is an important role for the EC to support the Member States in the development and strengthening of central EPC registers, especially in the context of a solution to tackle the private data issues, and tools for data analysis. The experience of different Member States regarding the systems of monitoring, compliance and quality check has to be examined and standardised methodologies formats of data gathering, according to best practices should be promoted.
There is need for guidance on the development of centralised EPC registries, not only to support the independent control system, but as a tool to map and monitor the national building stock. Therefore, the European Commission should provide further recommendations and enable the exchange of best practices towards functional EPC databases (i.e. methods for data collection and analysis and protocols for data sharing).
Embedding the role of EPC and EPC registers into national refurbishment policies will be the best driver to improve and sustain the EPC system over time.

Strengthening of Energy Performance Certificates (EPC)

In order to ensure compliance, every energy efficiency upgrade should be logged through an EPC or at the building's passport by an independent assessor, especially if the works are supported by public (both national and European) funds for buildings refurbishment. Standard formats to document the input data and to report the results of energy calculations make the EPC input data and results documentation transparent (e.g. Estonia, Belgium, France), and thereby facilitate compliance checks.
EPCs have also the potential to become "building passports" accompanying a building through its life cycle and include individual renovation roadmap (e.g. improvement proposals and energy renovation activities in a step-by-step approach) plus additional relevant information such as maintenance and reparations, involved (qualified) building professionals, energy consumption, thermal comfort and indoor air quality aspects.
Indeed, in order to become useful in individual buildings' improvement plans, EPCs should evolve towards more comprehensive, dynamic tools accompanying a building over its lifetime. Given the current and future ICT-prospects, this 'building passport' should be digitalised, which would facilitate the further development of available centralised databases.

ANNEX

The following tables summarise the data availability for some of the indicators and the key data sources that have been identified for 26 countries within the EU Buildings Stock Observatory project, with a special focus on energy performance of buildings. [2]

Legend:

(green)	rather good access to data
(light green)	data is available only partially
(yellow)	low data availability/expect difficulties
(red)	data not available

[2] For example, data on number of buildings and dwellings (available from EUROSTAT) have been collected within the project but are not showed in the following tables.

T.1.1 Building stock statistics

Indicators		HORIZONTAL DATA AVAILABILITY	AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
			NATIONAL DATA AVAILABILITY																									
Number of buildings/building stock units	k	ODYSSEE																										
Number of dwellings	k	ODYSSEE																										
Building floor area (and average floor area)	km²	ODYSSEE																										
Building stock decomposition by building or dwelling type	k,Mm²	ODYSSEE, DATA HUB; EUROSTAT																										
Building stock decomposition by construction period	k,Mm²	ENTRANZE, BPIE DATA HUB;																										
Building stock decomposition by size	k,Mm²	EUROSTAT																										
Building stock decomposition by location	k	EUROSTAT																										
Building stock decomposition by climatic zone	k																											
Building stock decomposition by occupancy level	k																											
Building stock decomposition by ownership status	k	EUROSTAT																										
New construction	Index, Mm²	EUROSTAT																										
Average energy performance of new construction	kWh/m²	ODYSSEE/ZEBRA																										
Renovation	def.																											
Energy renovation	k,Mm²	ZEBRA2020																										
Deep energy renovation	k,Mm²	ZEBRA2020																										
Major renovation (EPBD definition)	k,Mm²																											
Wall insulation improved from the original state	%	EPISCOPE																										
Improvements to at least thermal protection double glazing	%	EPISCOPE																										
Roof insulation improved from the original state	%	EPISCOPE																										
Average performance level reached after renovation	kWh/m²																											
Costs of energy building renovation	€/m²	ZEBRA2020																										
Demolished buildings	K																											
Rented out last year	K																											
Transactions last year	K																											
Stock of nZEBs	K	ZEBRA2020																										
Average energy performance of nZEBs	kWh/m²	ZEBRA2020																										

Table 1 - Results of data collection on energy performance of buildings within the topic "Building stock characteristics"

T.1.2 Energy Needs

		HORIZONTAL DATA AVAILABILITY	NATIONAL DATA AVAILABILITY																									
Indicators			AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
Final/primary energy consumption	ktoe	EUROSTAT																										
Energy consumption for space heating	ktoe	ODYSSEE (some) EUROSTAT (some)																										
Energy consumption for space cooling	ktoe	ODYSSEE (some) EUROSTAT (some)																										
Energy consumption for domestic hot water	ktoe	ODYSSEE (some) EUROSTAT (some)																										
Water consumption	Mm3	EUROSTAT																										
Energy consumption for lighting	ktoe	ODYSSEE (some) EUROSTAT (some)																										
Energy consumption for appliances (including cooking)	ktoe	ODYSSEE (some) EUROSTAT (some)																										
Energy consumption for ventilation	ktoe																											
Final energy consumption per end use per carrier (including for the space heating and domestic hot water)	ktoe	ODYSSEE, mainly residentail																										
Theoretical energy use	ktoe	EPISCOPE																										

Table 2 - Results of data collection on energy performance of buildings within the topic "Energy needs"

T.2.1 Envelope performance

		HORIZONTAL DATA AVAILABILITY	NATIONAL DATA AVAILABILITY																									
Indicators			AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
Air tightness	$dm^3/s/m^2$																											
Average U-value for overall building envelope	$W/m^2°C$	EPISCOPE INSIRE																										
Average U-value of doors	$W/m^2°C$																											
Average U-value of external walls	$W/m^2°C$	EPISCOPE INSIRE/BPIE																										
Average U-value of floors	$W/m^2°C$	EPISCOPE INSIRE/BPIE																										
Average U-value of roofs	$W/m^2°C$	EPISCOPE INSIRE/BPIE																										
Average U-value of skylight	$W/m^2°C$	EPISCOPE INSIRE/BPIE																										
Average U-value of windows	$W/m^2°C$	EPISCOPE INSIRE/BPIE																										
Disaggregation of type of glazing	No. of																											
Disaggregation of type of window frame	No. of																											

Table 3 - Results of data collection on energy performance of buildings within the topic "Envelope performance"

T.2.2 On-site renewable energy generation

		HORIZONTAL DATA AVAILABILITY	NATIONAL DATA AVAILABILITY																									
Indicators			AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
On-site renewable energy sources generation	Mtoe																											
Renewable electricity generation by PV panels	Mtoe	Eurostat, Shares Tool																										
Renewable heat generation by biomass	Mtoe	Eurostat, Energy Balances																										
Renewable heat generation by heat pumps	Mtoe	Eurostat, Shares Tool																										
Renewable heat generation by solar	Mtoe	Eurostat, Shares Tool																										
Renewable electricity generation by wind (small size turbines)	Mtoe																											
Conversion efficiency of the renewable energy technology used	%	2011/877/EU																										

Table 4 - Results of data collection on energy performance of buildings within the topic "On-site renewable energy generation"

T.2.3 Technical systems A) Space heating

		HORIZONTAL DATA AVAILABILITY	NATIONAL DATA AVAILABILITY																									
Indicators			AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
Disaggregation of buildings according to heating device coverage to main and supplementary	No.of	ENTRANZE																										
Disaggregation of buildings according to heating device capacity	No.of																											
Disaggregation of buildings according to heating system level	No.of																											
Average efficiency rate for space heating	%																											
Buildings/building units with central steam/hot water space heating system	No.of	BPIE																										
Buildings/building units with condensing boilers	No.of	TABULA / EC																										
Average efficiency rate of condensing boilers	%																											
Efficiency rate of the BAT condensing boilers	%																											
Buildings/building units with conventional boilers	No.of	TABULA / EC																										
Average efficiency rate of conventional boilers	%																											
Buildings/building units with combi boilers	No.of	TABULA / EC																										
Average efficiency rate of combi boilers	%																											
Efficiency rate of the BAT combi boilers	%																											
Buildings/building units with a built-in electric system	No.of	EC																										
Buildings/building units with central air space heating	No.of	EC																										
Buildings/building units with heat pumps	No.of	EHPA																										
Buildings/building units with reversible heat pumps	No.of	EHPA																										
Average efficiency rate of heat pumps	%																											
Efficiency rate of the BAT heat pumps	%																											
Buildings/building units with solar heating system	No.of	ESTIF																										
Buildings/building units with a stove	No.of																											
Buildings/building units with a fireplace	No.of																											
Buildings/building units with an electric storage heater	No.of																											
Buildings/building units with a portable kerosene / liquefied petroleum gas heater	No.of																											
Buildings/building units with a cooking stove	No.of																											
Disaggregation of space heating devices according to the energy source	No.of																											
Buildings/building units with heating on biomass – self produced	[No.of]																											
Buildings/building units with heating on biomass - purchased	[No.of]																											
Buildings/building units supplied with energy from heat and cold storage	No.of																											
Buildings/building units supplied with energy from on-site CHP	No.of																											
Buildings/building units supplied with energy generated by OTHER technologies.	No.of																											
Disaggregation of heating system according to the age of the space heating equipment	years																											

Table 5 - Results of data collection on energy performance of buildings within the topic "Technical systems - Space heating"

T.2.3 Technical systems B) Space cooling

Indicators		HORIZONTAL DATA AVAILABILITY		NATIONAL DATA AVAILABILITY																									
				AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
Disaggregation according to space cooling equipment coverage	No. of		ENTRANZE																										
Buildings/building units with reversible heat pumps	No.of		EC																										
Average efficiency rate of space cooling equipment	%																												
Efficiency rate of the BAT space cooling equipment	%																												
Age of the cooling system	years																												

Table 6 - Results of data collection on energy performance of buildings within the topic "Technical systems – Cooling"

T.2.3 Technical systems C) DHW

Indicators		HORIZONTAL DATA AVAILABILITY		NATIONAL DATA AVAILABILITY																									
				AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
Buildings/building units with a water heater/boiler	No.of		EC																										
Tank size	litres		EC																										
Age of the tank	years																												
Buildings/building units with a combi boiler	No.of		EC																										
Disaggregation of the water heating devices according to the main energy source	No.of		EC																										
Buildings/building units with electric boiler	No.of		EC																										
Buildings/building units with electric heaters (not heat-pump)	No.of		EC																										
Buildings/building units with other water heaters	No.of		EC																										
Average efficiency rate of water heating equipment	%																												
Efficiency rate of BAT water heating equipment	%																												

Table 7 - Results of data collection on energy performance of buildings within the topic "Technical systems – Domestic Hot Water"

T.2.3 Technical systems D) Ventilation

Indicators		HORIZONTAL DATA AVAILABILITY		NATIONAL DATA AVAILABILITY																									
				AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
Buildings/building units with mechanical ventilation (no heat recovery)	No.of		EC																										
Buildings/building units with mechanical ventilation (with heat recovery)	No.of		EC																										
Buildings/building units with natural ventilation	No.of		EC																										
Average efficiency rate of ventilation equipment	%																												
Efficiency rate of BAT ventilation equipment	%																												

Table 8 - Results of data collection on energy performance of buildings within the topic "Technical systems – Ventilation"

T.2.3 Technical systems D) Lighting

Indicators		HORIZONTAL DATA AVAILABILITY		NATIONAL DATA AVAILABILITY																									
				AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
Share of incandescent lamps	%		MELISA																										
Number of incandescent lamps in a dwelling	No.of		MELISA																										
Share of TL	%		MELISA																										
Number of TL	No. of		MELISA																										
Share of CFL	%		MELISA																										
Number of CFL lamps in a dwelling	No.of		MELISA																										
Share of LED	%		MELISA																										
Number of LED lamps in a dwelling	No.of		MELISA																										
Share of halogen lamps	%		MELISA																										
Number of halogen lamps in a dwelling	No.of		MELISA																										
Share of Others	%		MELISA																										
Number of other lamps in a dwelling	No.of		MELISA																										

Table 9 - Results of data collection on energy performance of buildings within the topic "Technical systems – Lighting"

T.2.3 Technical systems F) Cooking		HORIZONTAL DATA AVAILABILITY	NATIONAL DATA AVAILABILITY																									
Indicators			AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
Disaggregation according to the cooking equipment	No.of																											
Disaggregation of the cooking devices according to the energy source	No.of																											
T.2.3 Technical systems F) Electrical Appliances																												
Number of refrigerators in a dwelling	No.of	ODYSSEE																										
Number of freezers in a dwelling	No.of	ODYSSEE																										
Number of washing machines in a dwelling	No.of	ODYSSEE																										
Number of dryers in a dwelling	No.of	ODYSSEE																										
Number of dishwashers in a dwelling	No.of	ODYSSEE																										
Number of televisions in a dwelling	No.of	ODYSSEE																										
Number of computers in a dwelling	No.of	ODYSSEE																										

Table 10 - Results of data collection on energy performance of buildings within the topics "Technical systems – Cooking" and Technical systems – Electrical Appliances"

T.2.3 Technical systems H) Metering		HORIZONTAL DATA AVAILABILITY	NATIONAL DATA AVAILABILITY																									
Indicators			AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
Individual or collective metering	No.of																											
Availability of a thermostat	No.of	Eurostat																										
Thermostat types	No.of	Eurostat																										
Share of buildings with smart metering systems	No. of																											
Feedback system for smart meters	No. of																											
T.2.3 Technical systems I. Others																												
Dwellings/buildings with shading devices	No.of																											
Dwellings/buildings with PV-panels	No.of	Eurostat																										

Table 11 - Results of data collection on energy performance of buildings within the topics "Technical systems – Metering" and "Technical systems – Other"

T.2.4 Embodied energy		HORIZONTAL DATA AVAILABILITY	NATIONAL DATA AVAILABILITY																									
Indicators			AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
Estimated embodied energy of new construction	toe/dwelling or toe/building																											
Estimated embodied energy of deep retrofits	toe/dwelling or toe/building																											
Estimated embodied energy of major renovations	toe/dwelling or toe/building																											

Table 12 - Results of data collection on energy performance of buildings within the topic "Technical systems – Embodied energy"

T.3.1. EPC distribution		HORIZONTAL DATA AVAILABILITY	NATIONAL DATA AVAILABILITY																									
T.3.1. EPC distribution			AT	BE	BG	HR	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LV	LT	NL	PL	PT	RO	SK	SI	SE	UK
Stock with EPC	No of	ZEBRA 2020																										
Distribution of EPC levels for existing buildings	No of	ZEBRA 2020																										
Distribution of EPC levels for new buildings	No of	ZEBRA 2020																										
Distribution of EPC level per building size	No of																											
Value of the buildings	Euro/m2																											
Rent value	Euro/m2																											
EPCs issued last year	No of	ZEBRA 2020																										
EPCs displayed publicly	No of																											
Energy label impact on property market	%	EC																										
Energy label in commercial advertisements	%																											
Quality control of the EPCs	-	EC/CA EPBD																										
Penalties for non-compliance	-	CA EPBD																										

Table 13 - Results of data collection on energy performance of buildings within the topic "EPC Distribution"

Spatial data for modelling building stock energy needs

A UK perspective for the European Commission Joint Research Centre.

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Abstract

This paper describes the development of a 3D model of the non-domestic building stock of England and Wales. The model's purpose is to assess energy use in the stock, and study conservation options. The model combines digital maps and property taxation data to build a 3D representation in which separate premises are located within buildings, with floor areas on each level. For part of London, energy data at the individual meter level has also been coupled with this spatial model, allowing us to analyse energy use at the individual building level and energy use intensities per unit of floor area.

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Overview

Over the past 25 years spatial data and the use of Geographical Information Systems (GIS) has advanced from a little known research tool to a well known technology. More recently, with the arrival in car navigation and mobile phones equipped with Global Positioning Systems (GPS), the technology of GIS has gone way beyond the boundaries of what the early pioneers could have envisioned. In short, there is an abundance of spatial data compared to 25 years ago and the computing power available to analyse this data is no longer a barrier to these types of queries.

Despite this abundance of spatial data, when we try to model the activity within buildings the experience in the UK is that surprisingly little information is recorded consistently about the national building stock. This is despite the fact that some buildings remain in use for hundreds of years and if taken as a whole, the building stock is a high value national 'asset'.

If we combine the paucity of consistent, detailed information about the building stock with what we know about how much energy is used at this same scale (i.e. building by building) then there are large gaps in this information.

Research at the UCL Energy Institute is attempting to resolve this. Some members of the team have a relatively long history of work in this specific area, dating back to the 1990s (Steadman et al 2000). Significant breakthroughs have been achieved in the past 3 years with the full integration of a model of non-domestic floorspace with fine scale 3D GIS (1:1,250 scale) and the subsequent coupling of this stock model with energy meter data for individual properties and premises. We have called this model '3DStock'.

‘Premises’ and ‘buildings’

One of the first hurdles that is of fundamental importance when modelling any non-domestic building stock is the fact that 'buildings' may not equal 'premises' and 'premises' may not equal 'buildings'. Being able to model this relationship between premises and buildings is a critical step towards creating a detailed representation of the building stock. A premises is an extent of floor space with a single owner or occupant. A building is more difficult to define – indeed in what follows we will use a somewhat different unit, as we will explain. In everyday language of course a ‘building’ tends to mean a single structure, erected all at one time, in a homogeneous style and form of construction. In these terms, there can be different kinds of relationship of premises to buildings. Several premises can occupy a single building, as in the case of many tenants sharing one office building. One premises can coincide with one building, as is typically the case with churches. Or one premises can consist of many detached buildings on a shared site, as for example a secondary school, a university campus, or a large factory. With the domestic stock the situation is generally simpler. One ‘premises’ (the household) occupies one building (the house). In a block of flats on the other hand, many ‘premises’ (the flats) share a single building. There is a similarity with a multi-tenant office block. In other cases single buildings can be shared by domestic and non-domestic premises, as with flats over shops.

Data from the Ordnance Survey and the Valuation Office Agency

The main structure of the 3DStock model is assembled by bringing together existing data from two national sources. The first source is the Ordnance Survey – the UK’s national mapping agency – specifically the Ordnance Survey Address Base (OSAB) and Mastermap digital map products (Ordnance Survey 2015a, 2015b). The second source is the Valuation Office Agency (VOA) of Her Majesty’s Revenue and Customs (Valuation Office Agency 2015). In Britain, property taxes (‘rates’) are levied on premises, not on land as in many other countries. For this reason the VOA makes detailed surveys of all those premises – or what it calls ‘hereditaments’ – that are subject to rates.

The rating data for houses and flats are not publicly available. However the data for non-domestic hereditaments are released, in the form of two overlapping types of VOA records. The Rating List covers most hereditaments – with certain exceptions detailed below - giving the activities of the occupiers and the valuations on which the rates are paid. The Summary Valuation (SMV) database gives more detail for approximately 90% of these same hereditaments, including their floor areas. Here the ‘primary’ activity (e.g. ‘Commercial office’) is broken down into sub-activities (e.g. office, storage, kitchen, computer room etc). The database gives the floor areas devoted to these sub-activities on each floor level. The areas are measured according to different conventions, usually net internal area (NIA) or gross internal area (GIA). Analytical work carried out on VOA records and drawings in the 1990s showed that these measurements are very accurate, no doubt in part because they are open to challenge by ratepayers (Gakovic et al 1993). Both Rating List and SMV are updated continuously, with revisions and new entries prompted by applications for planning permission and building regulations approval.

Although the SMV database contains information on the majority of non-domestic hereditaments, there are several types of building that it does not cover. These include churches, central government offices, law courts and prisons. Some other types are included in the Rating List, for example hotels and pubs, but have no Line Entries or area data in the SMV. Information on floor areas for these types will have to come from other public and commercial databases.

Matching digital map footprints to hereditaments

Valuation Office Agency hereditaments can be matched to map polygons representing building footprints, by their respective addresses. Ordnance Survey Address Base holds a link in many (but not all) cases to unique address reference numbers (UARNs) in the VOA Rating List. OSAB also enforces compliance by local authorities with the British Standard for the formatting of address information, BS7666 (British Standards Institution 2006), and it coordinates and enforces the maintenance of Local Land and Property Gazetteers. For cases where this link does not exist, we have developed a special module to clean and match addresses. This module first attempts to clean non-BS7666 addresses into something close to BS7666, and then uses a number of different methods to find the closest match within the OSAB database. For the Camden, one of our case study areas, a 98% match rate was achieved for the 2010 Rating List.

The OSAB data can then be cross-referenced to topographic map data providing building footprints and other 'objects' viewable on detailed maps. The most consistent data set for the whole of England and Wales is the Ordnance Survey Mastermap Topography layer (OSTopo), which has polygons for buildings, roads, rivers and railways (Ordnance Survey 2015c). For the buildings, the address data are attached to points within footprint polygons. In this way Valuation Office UARNs can be matched to building footprints.

In practice the picture is however more complex than this brief account would suggest. First, there can be more than one address point within one footprint polygon. Second, there can be several addresses attached to each point. Third, a single 'building' may be represented by a group of adjoining polygons, only some of which are addressed in OSAB.

Taking these issues in order: the Ordnance Survey addressing can sometimes have a hierarchical structure, where there is just one unique property reference number (UPRN) for an address that might contain several hereditaments. For example a large office building ('Central House') might have a single UPRN, while a separate office hereditament in that building (e.g. 'University College London, first floor, Central House') might have a UARN, as might hereditaments on other floors. In other cases however a single building might have a 'parent' UPRN ('Central House'), which in turn has related 'child' UPRNs (e.g. 'University College London, first floor, Central House'), which in turn match to the individual hereditaments (UARNs). 'Unique Property Reference Numbers' do not therefore always correspond to a 'unique building'. These complexities are important when it comes to matching electricity and gas meter data, and for the units of construction defined for analysis in the modelling work, which do not equate simply to 'buildings'. These points are discussed further below.

'Polygon capture'

Then there is the problem that not all footprint polygons carry addresses. A typical case would be where a polygon on the street front corresponding to the major part of the building carries the address of a hereditament, but there are further unaddressed polygons corresponding to extensions at the back. Another frequent type of situation is where a shop or restaurant in a row of terraced properties has expanded into a neighbouring building, and only one of the two footprint polygons in question carries the address.

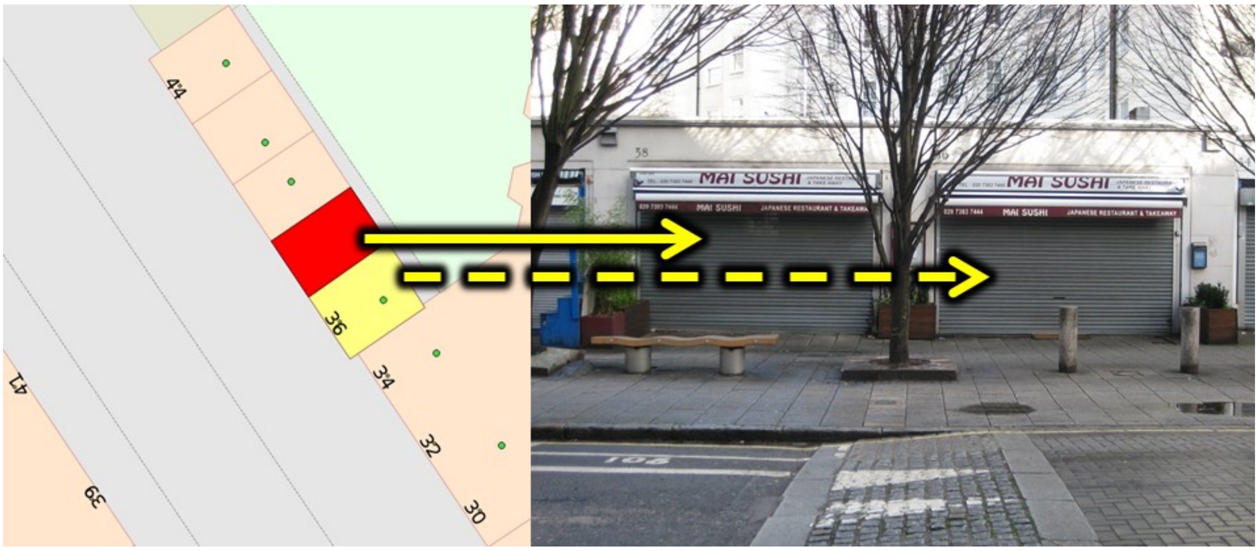


Figure 1. An example of ‘polygon capture’ where a restaurant has expanded into an adjoining building. The polygon at number 36 is the ‘addressable’ polygon for this hereditament. The SMV shows that it requires an area of 77 m^2 (GEA) but the polygon only offers 41 m^2. The unaddressed polygon at number 38 next door offers 37 m^2, which gives a combined floor area of 78 m^2. The software accepts this as an optimal match.

In order to cope with this problem, we have developed special ‘polygon capture’ software using a spatial topological model and combinatorial optimisation. This compares the area of the footprint polygon with the floor area on each level given by the VOA line entries for the hereditament in question (Figure 1). If these differ significantly – allowing for the respective conventions of area measurement – then the method seeks additional floor area in adjoining unaddressed polygons at the same level. The method finds the best solution that creates a combined footprint with the closest match to the figure given by the line entries. In cases where two addresses are competing for the same polygon, the solutions can be compared and the better result retained. In this way, the software can be run many times until an optimum solution is achieved.

This method works well for cases where a hereditament occupies several adjoining polygons. It cannot at present cope however with ‘campus’ hereditaments consisting of many separate buildings, since there are no simple criteria by which neighbouring (but not adjoining) polygons might be selected for capture. These problems can be overcome by using the Ordnance Survey 'Sites' product, which gives boundary polygons for campuses and similar sites with many buildings (Ordnance Survey 2015d). (Figure 2) The dataset is only available for a subset of the cases where this is required however, and so for other cases we use a digital version of the Land Registry property boundaries (HMLR, 2015) to identify cases where a number of buildings are contained by a single property boundary (Figure 3).

Figure 2. An example of a 'campus' where only the main building is 'addressed' (left) yet activity and energy use is probably spread across a number of buildings (right).

Figure 3. The thick black outline shows the land boundaries from the HMLR being used to identify all 4 detached buildings that make up the 'Corporation Yard and Engineering Depot'

Another issue that is unresolved at present can be thought of as the opposite of the polygon capture problem. It occurs when a hereditament falls in a polygon that is far larger than the ground floor area recorded by the VOA. This situation occurs when small hereditaments occupy space under the umbrella of a much bigger structure, such as a shopping centre containing many small shops, or a major transport hub like a mainline railway station with cafés and shops inside the 'building'. Additional geometrical data – specifically internal plans of these buildings – would be needed before the methodology could be applied in these circumstances. The danger of ignoring this situation is that activities or energy are assigned to the much larger polygon resulting in incorrect analysis.

With the exceptions of these problematic cases, once these steps are complete we end up with hereditaments that are 'stratified' and piled up on the relevant footprint or footprints to make three-dimensional 'pseudo-buildings' (Figure 4). The fact that the SMV database gives floor areas by floor levels means that hereditaments can be allocated to the correct level or levels (including basements).

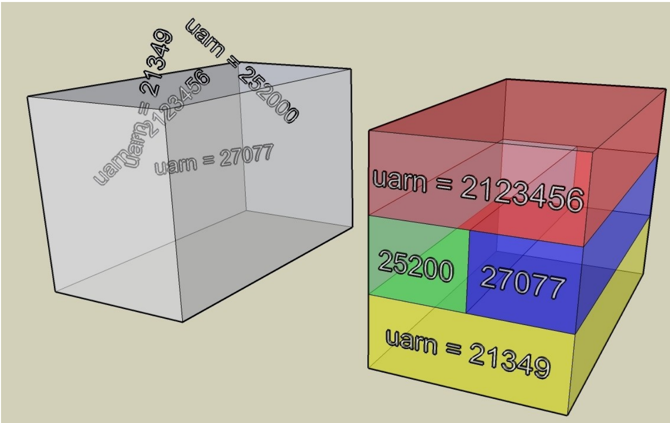


Figure 4. Premises (UARNs) matched to a building footprint but jumbled (left), and stratified by floor level (right).

The Self Contained Unit

Through this work it has become clear to us that when attempting to model activity or energy use in the non-domestic building stock, the 'building' is not a wholly satisfactory unit. This is because of the various possible relationships that can exist between premises and buildings, in particular the fact that one premises can extend across two or more adjoining buildings. Should buildings be taken as units, then premises could become split, and it would be difficult to relate meters and energy consumption to the different parts. For the present work we have instead adopted the Self Contained Unit (SCU) introduced by Taylor et al (2014).

Should one or more hereditaments occupy a building with a single detached footprint polygon then building and SCU coincide. The SCU concept comes into its own with groups of adjoining footprints. Consider the two situations in Figure 5, showing three terraced properties, numbers 15, 16 and 17 High Street. In (a) a single hereditament at ground level spans the two footprint polygons of numbers 15 and 16. The SCU (the black outline) is defined to contain the whole of both buildings. In (b) there is in addition a second hereditament spanning across numbers 16 and 17 at first floor level. Now the SCU (the black outline) must take in the whole of numbers 15, 16 and 17.

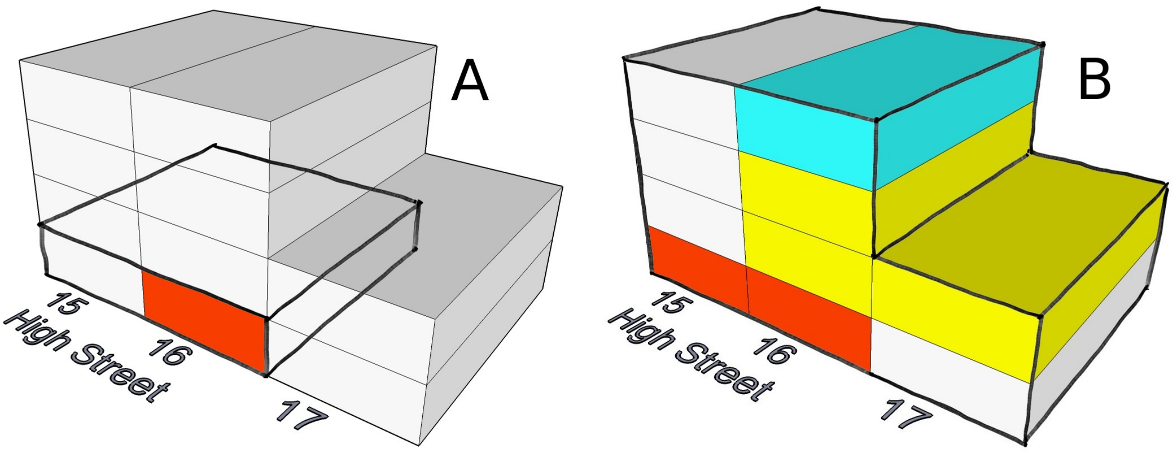


Figure 5. Self Contained Units (SCUs). Hereditaments are not broken between SCUs. In (a) a hereditament extends across 15 and 16 High Street at ground floor level, so the SCU (heavy line) spans the two footprints. In (b) another hereditament at first floor level extends across 16 and 17 High Street. Now the SCU (heavy line) must span all three footprints.

The basic criterion for defining the SCU is thus that it must not break hereditaments on any floor level. The SCU has two further properties that are of key relevance to energy analysis. First, it has a well-defined thermal envelope (roof and external walls) through which heat is lost or gained. This is of obvious importance for energy use in space heating, cooling and air conditioning. The second property is that it is generally possible to know the relationship between the totality of floor space within the SCU, and the total metered energy supplied to the SCU (as discussed further below). It would often not be possible to determine this relationship of floor area to energy use at the hereditament or even the building level. For example in a large multi-tenant office block, hereditaments corresponding to the many tenants might all have their own electricity meters, but all might share a common heating system with its own meter or meters controlled by the landlord. Again, there might be just one electricity meter for a hereditament that extends across two or more adjoining buildings. The picture can be very complex at these levels, somewhat simpler at the SCU level.

Figure 6. (left) A Self Contained Unit in Camden containing two buildings with a ground floor shop extending across both addresses. In this case the buildings are of similar age and construction. But in other comparable cases they might not be.

One drawback of the SCU, arising out of its very definition, has to do with the properties of the envelope. It is possible for different buildings making up one SCU to have different ages, different types of roof, or different wall materials and patterns of glazing (Figure 6). These could all in turn affect rates of fabric heat loss and gain. However this is an unavoidable dilemma, and there are only two choices: use the building as unit and subdivide hereditaments, or use the SCU and accept the problem of mixtures of fabric properties. We have chosen the latter.

We have created models of a number of regions including Leicester, Tamworth, Swindon and the London Borough of Camden. The examples from here onwards will focus on the model of Camden.

Once we have modelled a region at the SCU level we can begin to produce visualisations which show how the floorspace is occupied on each floor level. Figure 7 show one such visualisation for part of Camden showing all SCUs in an area along Camden High Street. The colours code for predominant activities in floors within SCUs. Figure 8 shows the breakdown by both activity and floor level for Camden, in the form of a Sankey diagram. Activities are distinguished at the left, in fourteen groups aggregated from VOA activity classifications. Offices dominate, followed by shops. Floor levels are given at the right. Shops unsurprisingly are mostly at ground level while offices are found on all floors.

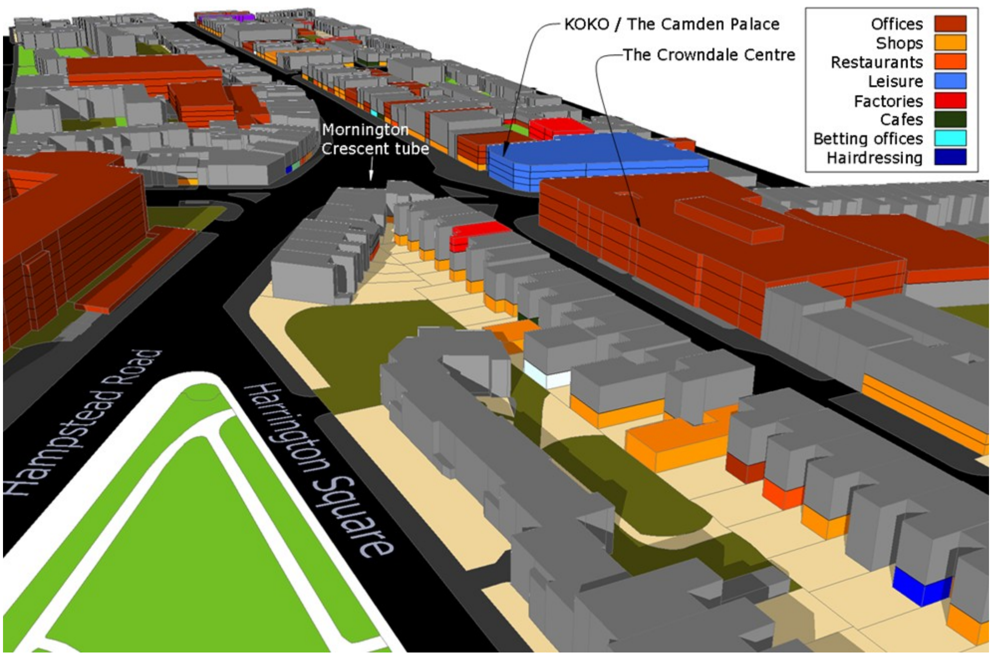


Figure 7. Three-dimensional visualisation of part of the Camden model for an area along Camden High Street. The dominant activity in each floor of each SCU is colour coded. Hereditaments that are not non-domestic (hence probably domestic) are shown in grey.

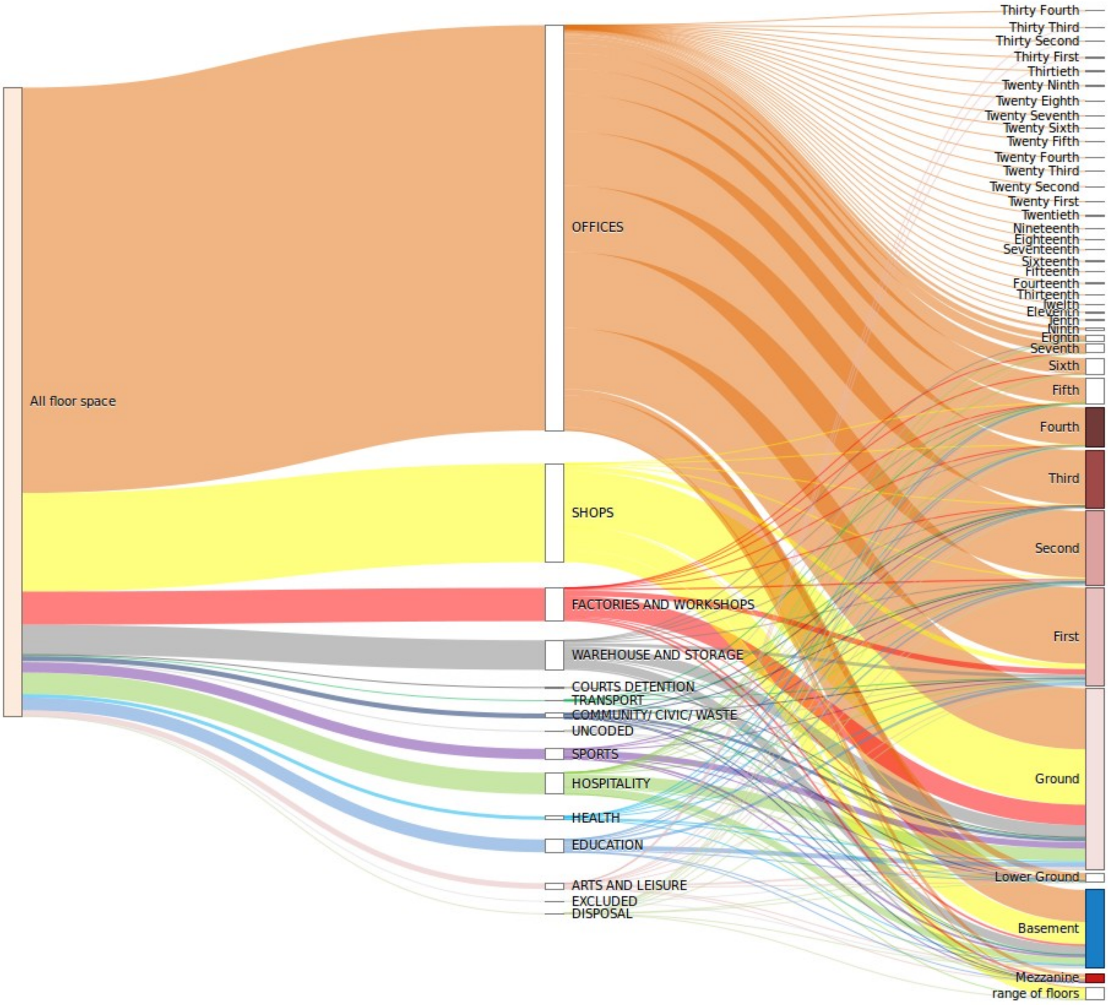


Figure 8. Sankey diagram to show the distribution of non-domestic activities in fourteen groups (left) between floor levels (right) in Camden. (Only floor area in the SMV database is included.) Shops are predominantly on the ground floor while offices are found on all floor levels.

Matching electricity and gas meter data to SCUs

The Department of Energy and Climate Change (DECC) has made 2011 gas and electricity meter data available to the project for all premises in Camden, both domestic and non-domestic. Use of these data is covered by strict confidentiality constraints. We will therefore discuss their processing and analysis in general terms, and present aggregated non-disclosive results.

Every electricity meter has a unique meter point administration number (mpan) with an address. The equivalent for gas meters is the meter point reference number (mprn). Both types of meter have been matched by their addresses to OSAB addresses (UPRNs). Through these they can be matched to the addresses of VOA hereditaments (UARNs). Successful matches were achieved automatically for 97% of gas meters and 99% of electricity meters in Camden.

Figure 9 gives a hypothetical illustration of the types of three-way relationship that can result. The meters here are all for electricity (mpans). The premises on the first floor at 42 High Street (A1 Hairdressing) is fairly straightforward. It is a child UPRN and has matched correctly to both a VOA hereditament and a meter, making it possible to assess electricity use in the hereditament as such. Downstairs however the VOA record for the Wine Bar and Premises has found the best match available, to the parent UPRN (42 High Street), despite the existence of a child UPRN for Bill’s Bar

– probably because of the difference between the two descriptions of the Bar. The electricity meter for this same hereditament has nevertheless matched correctly to the child UPRN for Bill's Bar. The result is a slightly less clear-cut relationship between hereditament and electricity use. On the other hand when we look at total floor area and total electricity use for the whole SCU at number 42, then the overall relationship is correct. Here lies the power of the Self Contained Unit.

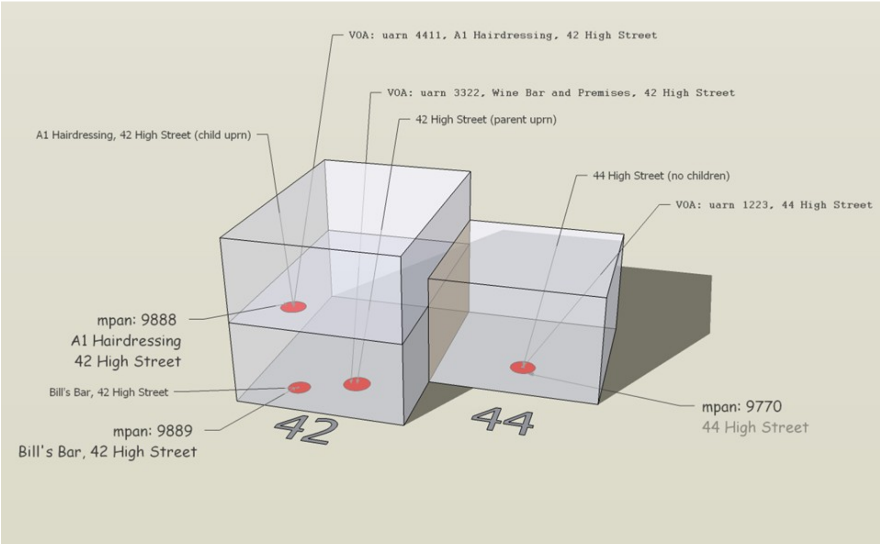
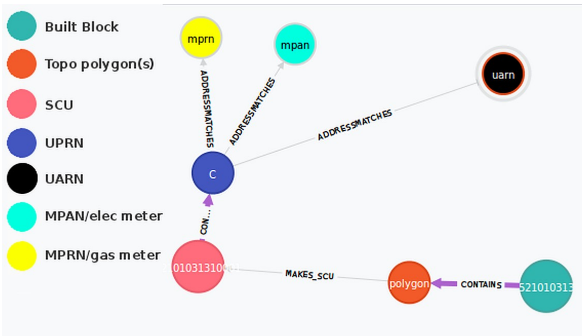


Figure 9. (left) A hypothetical illustration of possible types of match within SCUs of electricity meters (mpans) and gas meters (mprns) with OSAB addresses (UPRNs) and VOA hereditaments (UARNs). (See text for detailed explanation.) Even where some matches are not made, the overall relationship between floor area, activities and energy use is known, showing the power of the Self Contained Unit.

In actual cases such relationships can vary from the very simple to the highly complex as identified by Neffendorf et al (2009). We illustrate a series of real examples in Camden with all potentially identifying details removed. A SCU containing a single-storey shop (Figure 10a) has one hereditament (UARN), one gas meter and one electricity meter, all matched to the single UPRN. This is as simple as the relationships get. A two-storey SCU with one UPRN (Figure 10b) has two office hereditaments (UARNs), one shared gas meter, and one shared electricity meter.



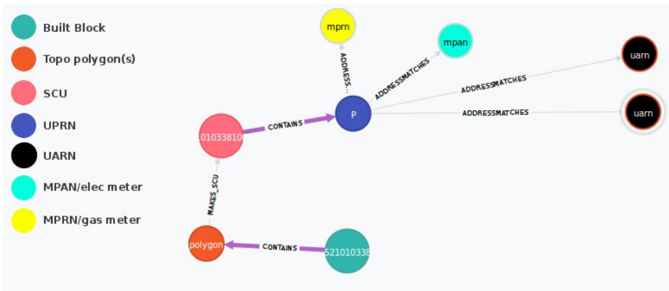
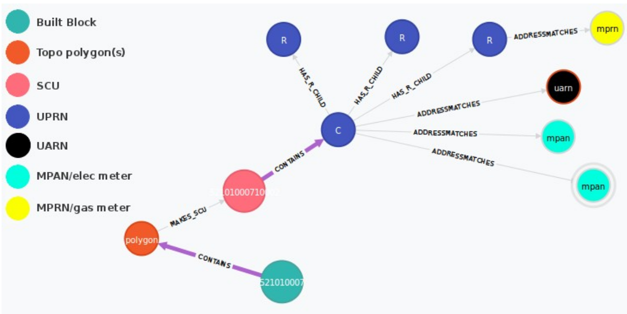


Figure 10. a (left) Single storey shop with one gas (yellow) and one electricity (cyan) meters. This and the subsequent figures show real examples of different relationships between meters, premises and footprints in Self Contained Units. The key distinguishes urban blocks (BuiltBlocks), building footprints in the OS Topo layer (topo), SCUs, Basic Land and Property Units (blpus, each of which has a UPRN), VOA hereditaments (UARNs), electricity meters (mpans) and gas meters (mprns).

Figure 10. b (right) Two premises in one building where they both share the gas and electricity meter

A four-storey SCU (Figure 11a) has one parent UPRN matched to a dry cleaner's on the ground floor, plus three domestic child UPRNs on the upper floors, one of which is a maisonette. One gas meter is matched to the maisonette, and two electricity meters to the parent UPRN. These are presumably shared between the dry cleaner's and the flats. A large office building SCU (Figure 11b) has a parent UPRN with fourteen child UPRNs, thirteen of which are matched to different VOA UARNs. There are twelve electricity meters and six gas meters matched to the parent UPRN, and a further two electricity meters matched to the fourteenth child UPRN.



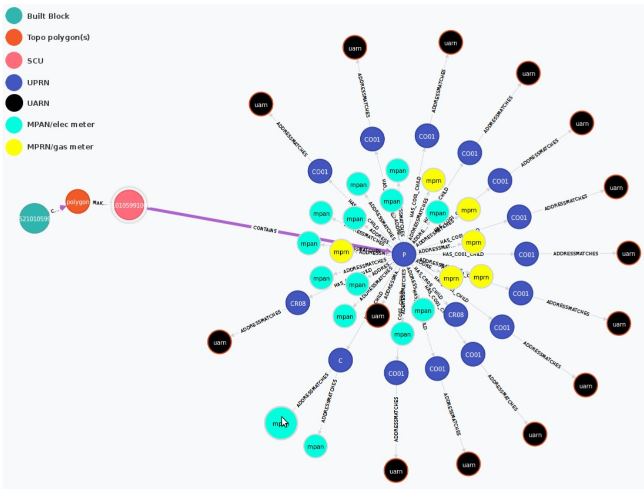


Figure 11. a (left) Relationships between meters, premises and footprint in a four-storey SCU with a dry cleaner's on the ground floor, and two flats and a maisonette above.

Figure 11. b (right) Relationships between meters, premises and footprint in a large multi-storey SCU containing fourteen office hereditaments.

Some large office building SCUs can nevertheless be simple in these terms. A multi-storey block under single ownership (Figure 12) has one UPRN matched directly to two UARNs, two electricity meters, and a gas meter.

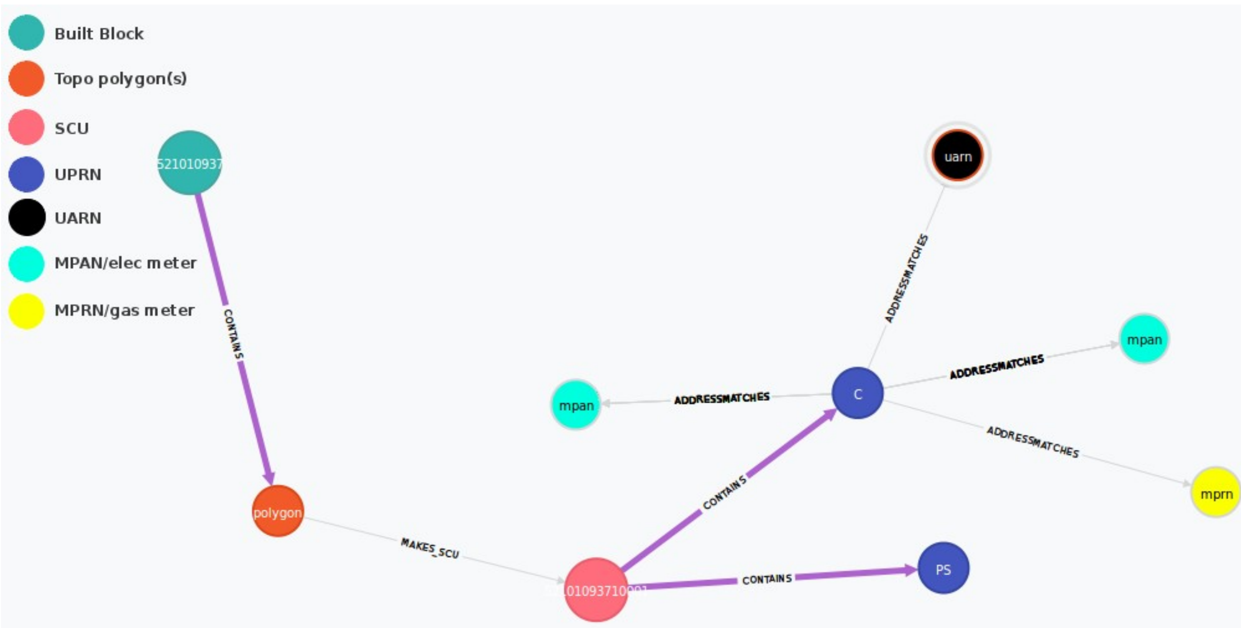


Figure 12. Relationships between meters, premises and footprint in a large multi-storey SCU with one office hereditament which has two electricity meters and one gas meter.

The more complex cases here reinforce the case for the SCU as a basic unit in which the overall relationship between floor area and energy consumption can be determined, even if the proportions of gas and electricity use supplied to different parts of the SCU are unknown. This would in many instances be impossible for separate premises/ hereditaments, as the examples have shown. The combinations of uses that occur in buildings nevertheless raise some problematic issues about what are actually meant by typical or benchmark values for energy intensity for specified activities. Should these be measured at the building/SCU level, in which case they refer to mixtures of activities? Or should they be measured at the hereditament level? But those hereditaments may not be independent in energy supply terms, and may for example share a heating or air conditioning system. Also they will share an envelope with other hereditaments.

Non-domestic 'energy epidemiology'

Energy meter data (gas or electricity or both) have been successfully matched, as described, to 5329 Self Contained Units in Camden. These data can be analysed in relation to activities and the results compared with energy benchmarks from other sources, for example Display Energy Certificates (Department for Communities and Local Government 2012). We are limited in publishing figures by confidentiality constraints. However, analyses of floor areas and the intensities of gas and electrical energy use are given for a number of the more numerous activity types. Note that Table 1 and Figures 13 and 14 refer only to SCUs that have been identified in each case as containing a single hereditament and no domestic (residential) addresses. This means there is a high probability that the SCU is a single building, containing a single non-domestic occupier. Also, meters where the consumption has a value of less than 2 kWh (including negative values) have been removed, as these records may be indicating that premises are not occupied, or that the meter is not 'live' and is merely being maintained in the energy supplier's database. Alternatively, the anomalous values may be due to factors of which the research project is not aware, such as the effect of annualisation of the data, rather than the provision of actual meter records.

	Principal activity in single-hereditament SCU					
	Floor area of sample SCUs, standardised to gross internal area (m^2)					
	Office	Shop	Workshop	Restaurant	Private school	Cafe
Count	387	344	69	56	28	27
Minimum	9	11	37	39	134	23
First quartile	150	54	74	106	405	48
Median	278	94	158	164	563	72
Third quartile	574	150	390	215	801	104
Maximum	17145	1223	18164	383	2172	157
Mean	722	127	574	166	645	79
Standard deviation	1555	141	2217	78	404	37

Table 1. Analysis of sample floor areas for selected types of activity in Camden. These are for Self Contained Units (SCUs) each of which contains just one hereditament with floor area and at least one electricity meter.

Table 1 presents the profile of floor areas for a sample of significant SCU activity types in Camden, where meters have been matched. Floor areas have been standardised to the VOA gross internal area (GIA) measurement convention. The samples clearly show the influence of outliers with large floor areas, especially in commercial offices, shops and workshops, but less so in schools, restaurants and cafes. For Figures 13 and 14 data have been purged of energy use intensity (EUI) values (presented as kWh/m^2/year) greater than three standard deviations above the mean within each activity class. Such high values are deemed to be unrealistic and are most likely due to questionable energy data, or errors/omissions in address matching.

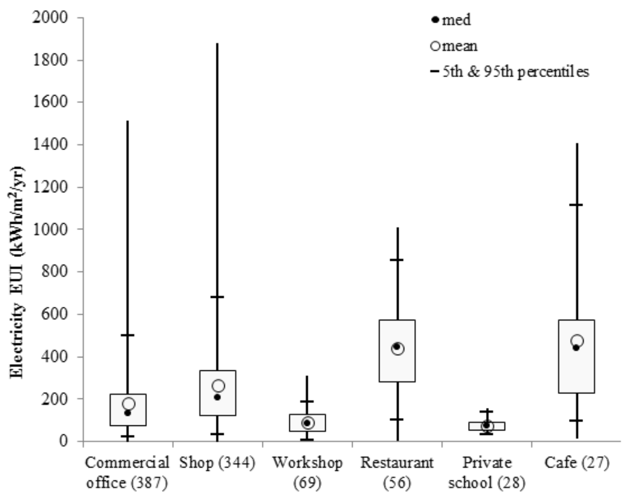


Figure 19. Analysis of electricity energy use intensity (EUI) for samples of Camden SCUs containing one hereditament. EUIs greater than three standard deviations above the mean have been removed prior to compilation. Floor areas are calculated to gross internal area. On the x axis, the numbers in parentheses indicate the size of the sample.

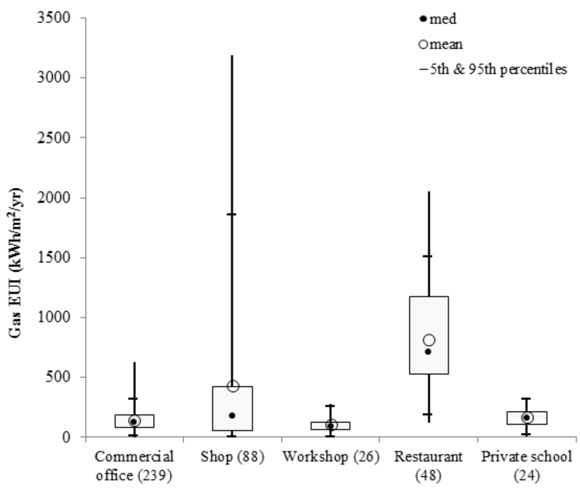


Figure 20. Analysis of gas energy use intensity (EUI) for samples of Camden SCUs containing one hereditament. EUIs greater than three standard deviations above the mean have been removed prior to compilation. Floor areas are calculated to gross internal area. On the x axis, the numbers in parentheses indicate the size of the sample. Cafes omitted due to small sample size.

Except for private schools, the spread of EUIs is extremely wide within each activity, considering these are cleaned data. Only restaurants and private schools have something close to a normal distribution in both electricity and gas use, whilst electricity EUIs in workshops are slightly skewed. High outliers are tending to skew the results in other activity types, and the middle two quartiles (represented by the boxes in each figure) cover a broad range of values in most activities. This degree of variability in the annualised meter consumption data is testament to the difficulties of modelling energy use in the non-domestic sector.

Beyond this, it is possible to study consumption in relation to characteristics of building geometry and construction, measured from or associated with SCUs. To do this for such a large sample of non-domestic premises/ buildings has not previously been possible. For the domestic stock of Britain, DECC and the Energy Saving Trust have developed the Homes Energy Efficiency Database (HEED, now part of NEED), which has made it possible to study gas and electricity consumption in relation to a range of built form and household characteristics for millions of dwellings (Hamilton et al 2011). This type of large-scale statistical approach has been called ‘energy epidemiology’ by analogy with epidemiology in medicine, where health outcomes in populations are studied in relation to lifestyle, environmental and other variables (Hamilton et al 2013). The present work opens the prospect of a non-domestic energy epidemiology.

Conclusions

Significant breakthroughs in the past few years mean it is now possible to create detailed spatial models of activity, floorspace and energy for the non-domestic building stock of England and Wales. This can be achieved by automated procedures and can be rolled out to any region of England and Wales. To achieve this kind of modelling we have found that it is essential to take into account the relationship between premises and buildings and to develop a modelling method that can cope with these often complex relationships. At present, much of the data we are trying to align has no direct spatial element to allow its integration into a GIS. Our experiences with the models have shown that the development of bespoke software that enables the address matching of often fuzzy addresses to a spine of 'correct' addresses is an essential first step in this process. In most cases, but most particularly in urban areas, it is essential to be able to model these activities in 3D so that the 'stratification' of premises in say a multi-tenant office block can be handled. The methods we have developed are automated which makes it possible for us to model any region of England and Wales in this manner.

Our aim was to model the energy requirements of the building stock using energy data derived at the end user meter level. This meant that the model structure we adopted was of great importance if we were to avoid producing statistical outputs that obscured the finer details of the activities within these buildings. Our experience is that if this step is ignored then there will be cases where the energy use per building is modelling something that could involve mixed activities, and even a mixture of domestic and non-domestic activities which would lead to misleading statistical conclusions.

In a similar way there will be cases where energy use has to be spread across many buildings, as is the case when a premises occupies a campus (for example a school) or a large factory uses several buildings on one site. Cadastral mapping can help here, although this cadastral mapping may also need to be modelled in 3D if at the same time it needs to be able to cope with the increasing complexity of the premises to buildings relationships that are theoretically possible and can occur in densely built up areas.

For the work presented, our aim was to produce energy use standardised by area (for example EUI of kWh per m^2 of floorspace). To do this a reliable measurement of floorspace within the buildings is required. Our experience has been that when this floorspace data contains even minor errors, it can have a large impact on the EUI's produced. Estimating this floorspace from building footprints should be practised with caution.

Our aims from here are to integrate further datasets on the building stock such as age of buildings, construction materials, glazing ratios and roof types. This would open the prospect of a programme of statistical work on correlations and the possible derivation of types, by which unknown properties might be inferred from known properties. These results could be used in developing models of other locations. Work on basements has already shown that their incidence and size is related to building age. Work in the 1990s using detailed measurements of glazing areas and glazing types in a sample of 100 non-domestic buildings showed strong relationships between glazed area and floor area in day lit built forms (Gakovic 2000).

We hope to be able to roll the data out to much larger parts of England and Wales. However access to individual meter data at the level of detail described in this paper is not possible without special access being granted by central government, and so we may have to turn to modelled data or spatially aggregated meter data for this future work. This will add complications and uncertainties to what is already a complex model.

Data sources:

Data provided by the Valuation Office Agency contains public sector information licensed under the Open Government Licence v1.0.

Map data © Crown Copyright/database right 2012: an Ordnance Survey / EDINA supplied service.

Gas and electricity meter data was supplied by the Department of Energy and Climate Change (DECC).

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Energy and Location: CIMNE point of view

1. CIMNE and BEE Group Introduction

CIMNE is a consortium between Government of Catalonia and the Polytechnic University of Catalonia. CIMNE has the experience and reputation gained through participation in more than 910 R&D projects with the financial support of the European Community, and various organizations as well as Spanish and International enterprises. Within CIMNE, the Buildings Energy and Environment (BEE) Group is an independent research group of around 20 researchers, focussing their R&D activities on methodologies and tools for the reduction of CO 2 emissions in the urban environment. Within this focus, work is organised along three lines: applied research for the energy retrofitting of buildings and neighbourhoods; applied research for the introduction of renewable energies and energy efficient methodologies in the building sector and consultancy and assessment to municipalities to enhance their sustainable urban development. CIMNE BEE Group are dedicated to achieving the highest possible energy performance in as many buildings as possible, by the practical application of research results in a real, business oriented, environment. In practical terms this means practicing what we preach.

2. Experiences on Energy and Location

CIMNE-BEE Group has been working on projects and development of tools and services to optimise the energy consumption in public, private and residential buildings for more than 15 years. In this section we want to share the lessons learned during that time, believing that the experiences we describe can show how treatment of data combined with the appropriate delivery of results to end users improves the energy management of buildings and achieves energy savings. But for doing this you need the right data and methodology.

A first group of projects are several projects for improvement of the energy management in buildings through ICT, developed from 2009 to 2015. The projects use monitoring of key parameters related with the energy consumption in the buildings, available third-party data (weather data, consumption of energy companies, etc...) and treat analytically this data displaying the results for different types of end users (building managers, occupants) with the objective to achieve energy savings.

We can distinguish two subgroups of projects in this field. The first one is focused on the residential sector, where we have developed three projects (eSESH, BECA and Encerticus (www.med-encerticus.eu)). These projects provided services to 250 homes in Spanish pilots s led by CIMNE and more than 5,000 homes in total. These projects allowed CIMNE to improve the knowledge and service related to data processing and visualization to the end user along of time. Paper, web and mobile app were used as user interfaces.

Figure 1: Example of final visualization addressed to final residential users (Encerticus)

In all of these projects a significant energy savings has been achieved. The average savings in each final energy source have been: 6% electricity, 4% thermal energy, 4 % water.

The second group of projects are based on the same concepts as the first one but the final target are public buildings. In these projects is very important the correct identification of the various types of users who have influence on the energy consumption of the buildings and the information they need. The visualization takes special importance in this case, as the different types of users need different information. A good example is the SmartSpaces project (www.smartspaces.eu) where CIMNE, as leader of the Spanish pilot, developed analytical tool and visualization interfaces for building users at all levels, providing services to 30 buildings and saving 30% of the thermal energy and 10% electricity.

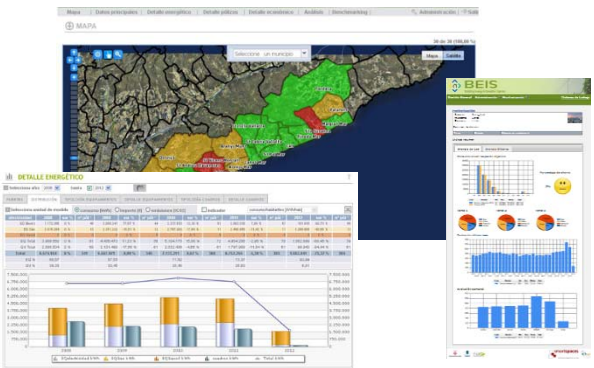

Figure 2: Some example of visualization for different user's level.

Another example of successful application of ICT-based services for energy efficiency are those provided by the company INERGY (www.inergybcn.com) created by CIMNE. INERGY has been offering services since 2005 to around 3,000 public buildings in more than 400 municipalities, and has achieved sustained savings, between 2% and 10% (depending on service given).

Lessons learned from these projects:

- The users in the residential sector are not prone to make investments in energy services, but the majority of them are interested in receiving this kind of services without cost.

- In many cases the data necessary for the services already exists in utilities or public authorities and the investment can be minimal.
- Not all buildings have a sufficient savings potential that justifies the investment in additional monitoring equipment.
- Training and motivation of users is a key to achieve real savings.

Analysing the lessons learned from these projects we realized that the best channel of communication with the residential user were utility companies. For these reason we developed the EMPOWERING project (www.iee-empowering.eu) where services for awareness and empowering end users are given to more than 350,000 customers, of four utilities around Europe (Austria, Italy, France and Spain). In this project CIMNE is responsible for the analytical data (using our own Big Data Analytics system) and communication with utilities and existing databases (cadastral, weather data, etc ...) and the utilities are responsible for displaying the results to their customers. The services received by end users can include in:

- Comparison with similar households (by power, tariff, Postal Code,...) .
- Indications of performance improvements over time.
- Consumption-weather dependence.
- Detailed consumption visualization, and breakdown.
- Personalised energy saving tips.
- Alerts (high consumption, high bill, extreme temperature, etc.).

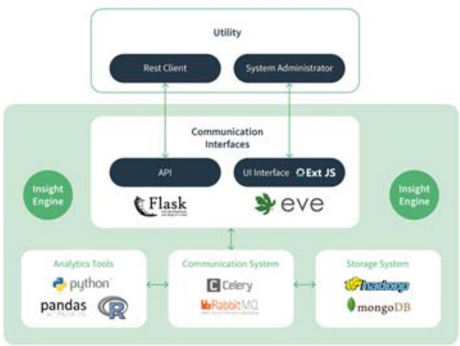

Figure 3: work scheme of CIMNE Big Data system

Figure 4: Some examples of visualization to final customers.

The average savings of customers who received this type of services is around 5%, both in electricity and thermal energy.

Given the success of these services CIMNE started marketing the services developed in Empowering, under the trade name BEE Data (www.beegroup-cimne.com/solutions/solutions-for-utility-companies/) and now the service is provided to 8 utilities and approximately 450,000 final users.

Lessons learned in EMPOWERING:

- The user interfaces and the personalization of the information shown is a key to achieve savings

- To engage users to these services the reports attached to their bills is one of the best options.
- Sending the information to large group of users without previous consent (opt-out) is better that offering the services through voluntary registration (opt-in)
- Working with anonymized data permits to preserve user privacy

Alongside Empowering which partly has solved the energy management services of residential buildings, at least at the level of end-user or owner, It is necessary to dig deeper into improving the management of public building stock and improve the services to decision-makers in order to take full advantage of the existing and usable data for energy management. The project SEMANCO (www.semanco-project.eu/) is an example of that approach.

This project aimed to make a semantic integration of existing data in multiple databases that were scattered in different organizations to improve the support on decision making at the political level and public authorities, and thus, improve the management and urban planning by municipalities.

In this project we realize that integration of some public data, with effort, was relatively easy to acquire and work them (eg. cadaster, weather data, etc ...) others data such as population size, GDP, etc .., they were accessible but only at the municipal level or by zip code and, finally, other data exist such as energy consumption or specific building descriptions that are impossible to achieve at any level (if you work with large utilities). But we realized that there are still many public regulations and practices that oblige the collection of valuable building information on paper, not accessible for automatic processing. An example is the data from the technical building inspections (ITE) in Spain.

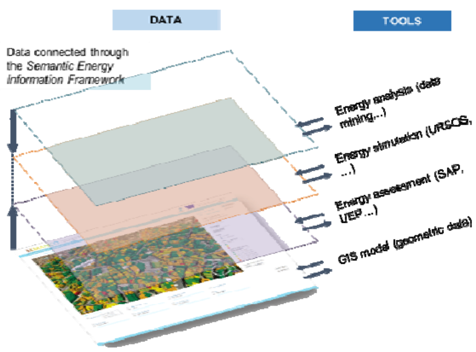

Figure 5: work scheme of SEMANCO system

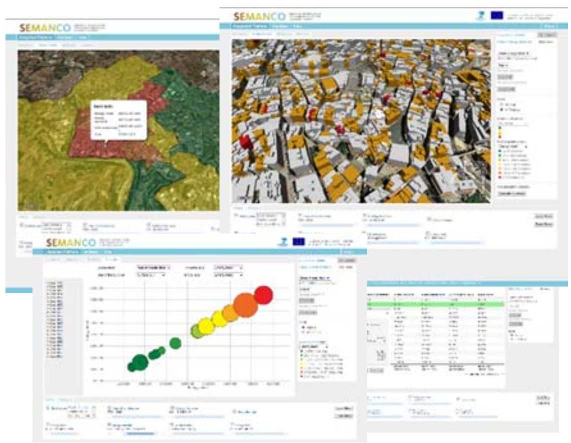

Figure 6: Some examples of visualization of SEMACO project.

To continue with the project, we had to work with simulation and modeling of demand, using as base the data we actually got. Thus we could develop the different visualizations of data that were previously marked as SEMANCO project objectives.

Learned lessons in SEMANCO project:

- Not all available data to facilitate energy management are really accessible.
- Public authorities are not prepared to make the data accessible to users. Users that previously had been requested them a lot of information of their building and facilities. Due to there are many records still on paper (projects, maintenance, etc...).
- "Personal data" is very difficult to access or use due to the data protection law. Using aggregated data (user averages) is a possibility.
- Use of open source software facilitates the massive exploitation of the results in such projects, as it permits the collaboration of different service providers.

3. The Catalan initiative on E&L

After exposing the projects we have done in CIMNE during the last 10 years related to Energy and Location, together with lessons learned in them, we want to expose our view on the future possible exploitation in Catalonia and the opportunities brought by the signing of the "Catalan Strategy for Energy Rehabilitation of Buildings". This agreement was signed in 2014 by more than 70 organizations involved in the energy management of buildings in Catalonia.

This strategy sets clear and ambitious targets for intervention in the Catalan building park to promote the reduction of energy consumptions of buildings by 2020. These objectives are shown in the following table:

Field	Goal
Energy	Reduction of 14% of final energy consumption of the residential and tertiary buildings in Catalonia (equivalent to 558kTep)
CO2	Emissions reduction of 22% of CO2 emissions of the residential and tertiary buildings in Catalonia (equivalent to 2.6 million TnCO2)
Cost savings	Savings 21% of the economic cost of the residential and tertiary buildings in Catalonia (equivalent to 800 million €)
Buildings	Intervention in 61% of the residential and tertiary buildings in Catalonia (790,672 buildings)
Mobilized investment	Investment of 1,400m euros in 120 macro energy renovation projects with public and private funds.
Jobs	Creation and / or recycling of more than 14,000 workplaces.

To achieve the objectives of this strategy has been prepared the action plan which is divided into five main lines:

1. Information System
2. Involvement and training
3. Innovation products and services
4. Organizational Model
5. Investment program and financial mechanisms

CIMNE leads the Information System line and actively participates in the others in order to achieve the objectives of this strategy.

The information system aims to collect all information that is useful for the improvement of the energy management in buildings (both previously recorded information, such as information not collected yet but that must be collected), to process and analyse data, returning valuable results to the different stakeholders involved in the energy management of the buildings.

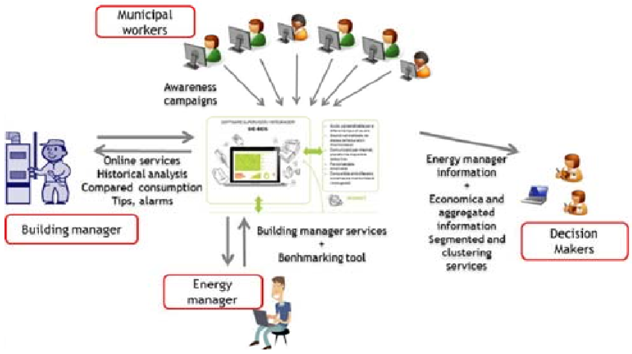

Figure 7: User interaction for Catalan Building renovation Strategy

Implementation of the Information System

The implementation and development of the Information System is structured in 5 phases within the period 2014 -2018 which are described in the table.

Buildings	Year	Inputs	Tasks
F1- Catalan Government Buildings pilot (~ 500)	2014	Cadastral and meteorological data, key Id (cups, ref. cat), EEM (investment, application date)	Gather the information, pre-process and store it, prepare the outputs for Authorities.
F2- All Catalan Government Buildings pilot (4000)	2015	Real consumption data (monthly) thermal and electrical. Other descriptive data. Energy building certification.	Development of methodologies and analytics, outputs for all users.
F3- Catalan Municipalities + extend de system to other EU regions.	2016	Consumption data (hourly) of public entities. Energy Efficiency Measures.	Big Data analytics and improvement of the visualization.
F4- Tertiary sector	2017	Business and company description data. Private consumption data.	Analytic development for the private sector.
F5- Residencial	2018	Residential building description data. Residential sector consumption.	Analytic development for the residential sector.

Phase 1: The development of the strategy in 2014 begins with a pilot consisting of a group of buildings belonging to the Government of Catalonia (400 of 4000 buildings available), where the information system is implemented and connected to existing databases for collecting additional information necessary for improving the energy efficiency. The system manages also the energy saving actions applied in buildings as well as the date and investments made in the previous period (2012-2014).

Cadastral data	All Catalan Buildings

Building energy certification	All Cert Buildings
Meteorological data	150 stations
Building description (typology , CUPS, cadastral reference)	~400 buildings
Energy Efficiency Measures (EEM) applied, application date.	~1500 EEM
Investment in EEM	~ 20 M€

Phase 2: For this phase, in late 2015, are given access to all users with buildings of the Government of Catalonia (4000 buildings), and the data of electricity and thermal consumption (1800 contracts) is added. All users have access to the monitoring reports and evolution of buildings.

Decision makers in the administration: They have a geolocation on interactive map to see the status of the various analysis general state of building park. A status report with number of buildings, energy state of buildings, implemented measures, with economical investment and personalized treatment is also generated by:

- By department.
- By type of building (schools, offices, etc ...).
- By geographical area.

The building responsible person will receive a report that provides him with overview of building energy consumption including the evolution of building consumption compared to the historical, consumption compared to similar buildings, evaluation of return on the measures, and suggestions of measures to implement depending on their typology (measures more implemented with successful in similar buildings).

Figure 8: Building responsible visualization example

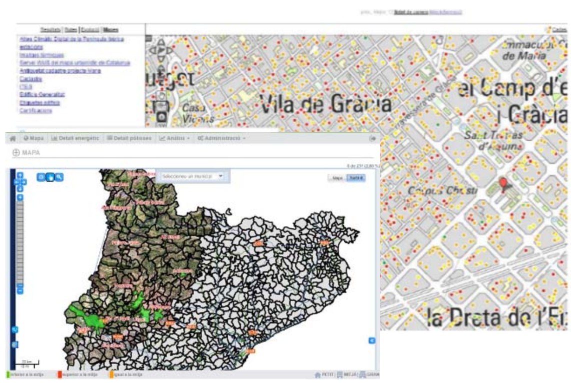

Figure 9: Authorities visualization example.

Phase 3. The target set for 2016 is to integrate all the buildings of the Government of Catalonia and also give access to the most important municipalities in Catalonia progressively, with special attention to those participating in the CoM. In parallel, is expected extend the initiative to other European regions. The fund to do that will be provided by the EDI-Net , EE07 program of H2020. This project will be extended to the cities of Leicester and Nuremberg in the first year of the project and in the second year, the project aims to expand to 150 cities (municipalities that are partners of "Climate Alliance").

Phase 4: In this fourth phase aims to adapt the system to give service to private buildings, initially tertiary sector (hotels, supermarkets, shops, bars, etc.). The necessary adjustments will be in obtain data necessary for management in the private sector and improving analytical for classifications, similarity, and customization by sector.

Phase 5- For 2018, the goal is to also enter the residential buildings of Catalonia. In this way, the system could reach 12 million of Catalan buildings processed. The tasks to be performed are the same as in Phase 4 but for the residential sector. We see that the most important limitation is the obtaining of the additional data, being the analytical part similar to those developed in the Empowering project.

4. Conclusions

From experience in previous projects we'd like conclude the most important issues that are necessary to take into account when someone want start one project related to Energy and Location, these are:

- Final users and their needs must be the focus of any application or data processing. Process and visualization of data without taking into account the final user needs and knowledge are useless.
- Public authorities at all levels should be closely involved in any initiative that seeks to use data available to the government.
- There is potential to treat personal data without infringing data protection law, but it is vital to be clear about the goal we want to achieve with your treatment.
- The use of open-source tools can guarantee much more profitable development of demonstration projects, replication and research. Also make easy the collaborative future developments or favoring exploitation by third parties, reducing the initial investment and fixed costs of the systems.

In the other hand, we think that the "Catalan Strategy for Energy Building Rehabilitation" can be an appropriated candidate for a pilot to test the INSPIRE directive due to the structure of work and the necessary involvement of the authorities as a key facilitator of data. As can be seen from the marked in the objectives of the Phase 1 and 2, which are the phases that are already developed, have been carried out successfully. Phase 3 is also on the way to reach its goals. For this reason, we think that the rest of phases should be accomplished with success.

Boverket

Swedish National Board of Housing, Building and Planning

Date
2010-11-12

The Swedish EPC register

The Swedish National Board of Housing, Building and Planning is a central government authority and is responsible for the Energy Performance Certificate (EPC)-register. The first version of the EPC-register was released in September year 2007.

Today there are nearly 600 000 buildings in the EPC-register. Everybody can access some basic information for the EPC from our website.

Our register contains all type of buildings, new buildings as well as existing buildings. There are three main types of buildings: single family houses, multifamily houses and non-residential houses

In year 2014 we made two major changes in EPC, first we changed the design of the certificate. From a fixed scale **(picture 1)** for every building not taking in consideration what kind of building in, which use the building has or where in the country it is placed. Today we use a common A- G **(picture 2)** scale where the energy performance is related to the different values of the energy performance for new buildings.

Secondly we have changed the way to access the register to perform EPC: s. Before year 2104, we have a system with accreditation, meaning that a company has an accreditation and that not all of the employed in the company has to be certified to perform EPC:s

From 2014 we have change the way to access the register and perform EPC:s where everybody has to be certified by an accredited company. There is an exam as one part of the certification, the persons have to have relevant education and some years in work practice in the area buildings and energy. Every certification has to be updated within five years.

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Date
2010-11-12

Using GIS

We have recently used our GIS (Geographic Information System)-application to deliver a map, with indoor radon concentration measures in Sweden, to JRC **(picture 3&4)**. Most of the values have been downloaded from our EPC-register. There is no obligation to perform a radon measure in all buildings in Sweden so therefore not all EPC: s include a radon measurement.

Radon is a part of the information in the EPC:s in Sweden, radon is not directly connected to energy, but the principle is the same of how the data from register works.

The map was divided into 10*10 km grids by our GIS-application, and we used the unique identification number of the buildings in the EPC-register to get the coordinates of central point of the buildings. These coordinate where downloaded from the authority that is responsible of the cadastre. With this information we could gather a number of radon measurements in the different 10*10 km square by using the GIS-application.

The GIS- application produces an average value of the radon in each square, by summing the values of measurements and divides it by the numbers of measurements.

We have used the EPC-data in the same way as the radon map delivered to JRC, for internal use. The map was divided in squares of 250*250 m using the energy performance to display the average in each area to see the differences in the country.

Validating the information

All building in Sweden have a unique identification number, with a single number prefix and a number (1-234567). By this number it is possible to connect to coordinates. This number follows the building through its lifecycle and is never reused.

When we started the register for EPC: s we did not validate the identification for the buildings and therefore we have old EPC: s where we cannot identify what building the EPC refers to. The energy experts had to fill information about the identification but they were not used to identifying buildings. The energy experts and the owner of the buildings know the name of the property and the addresses, but that was not enough to get the right identification of the buildings.

As a first step we verified the name of the property and that the property was placed in the right municipality, by an online service to the cadastre. But we did not know if it was the right building at this time.

In the next step we got access to all information of buildings and properties. With this information we used our own GIS-server with a map and put a layer with the buildings upon it, using there coordinates. This was the moment when we introduced the map in the application to support the energy experts to identify the buildings **(picture 5)**. Using this technique, we nearly have 100% correct identification on every building in the register from this date.

We have recently changed the way our system access this map. Today we are accessing the map in the application through a web-service from the authority that is responsible for the cadastre.

The risk using another service is the reliability, but we felt that it was an insignificant risk compared with the maintenance of the map, so we decided to use this web-service. The map has to be updated periodical because of changes in properties. Updating and cashing the map is process that we felt too hard to handle on our own. The building where spotted in the right place on the map, but the information in the map was not always correct.

The energy expert has to choose municipality and fill the name of the property to get to the information in the map. The property can contain a number of buildings that will be marked as spots in the map. The energy expert chooses the building by clicking in the map and the information will be filled into the form.

As we know that the information about the buildings identification are correct we can link this information to other specific information of the buildings

If there will be a mistake, by the energy expert, choosing the wrong building at the wrong property, we have a possibility to correct this information, using the same map-support as the energy experts.

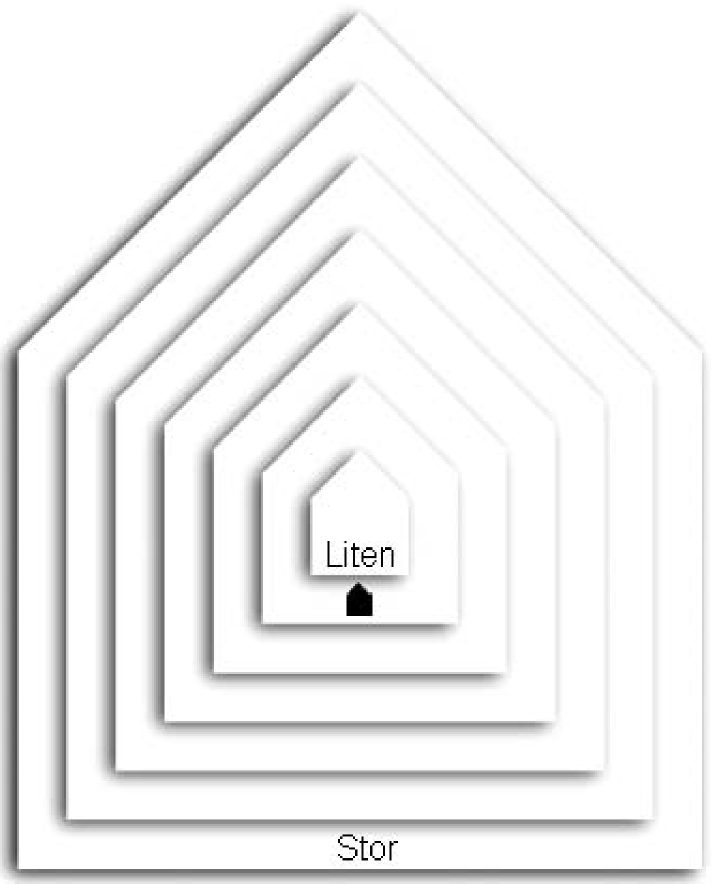
In the EPC- application we have validation in most of the fields that have to be filled, sometimes the validation lead to a stop, for impossible values. Sometimes the validation is a warning to alert the energy expert that something might be wrong. In some cases we have fields that are checked in correlation to each other. There are even guidelines of every field how to fill the values, accessed by hoover in the field **(picture 6**).

It is important not to have too much warnings/stops that make the application annoying and hard to interact with.

It is important that there is possibility to use the form to fill information even though it is an extra ordinary building for example a really large building.

Date
2010-11-12

Picture 1



Picture 2

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Swedish National Board of Housing, Building and Planning

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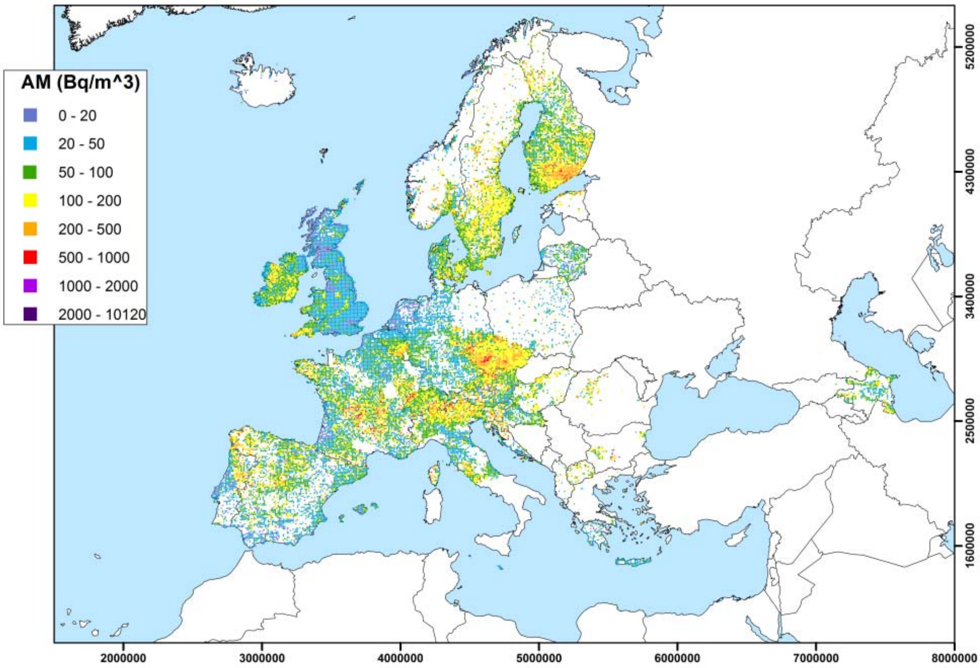
2010-11-12

Picture 3

European Indoor Radon Map, October 2015



Arihmetic means over 10 km X 10 km cells of long-term radon concentration in ground-floor rooms.
(The cell mean is neither an estimate of the population exposure, nor of the risk.)

Source:
European Commission, Joint Research Centre (JRC),
Institute for Transuranium Elements (ITU), REM project

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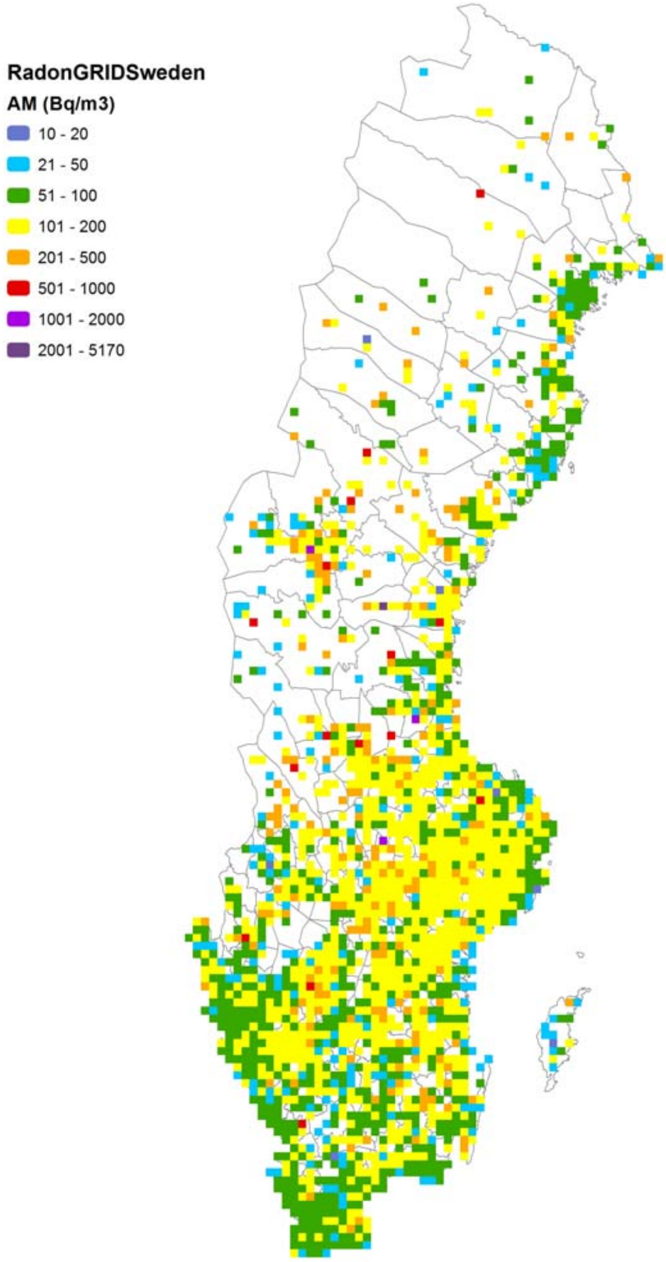
Picture 4



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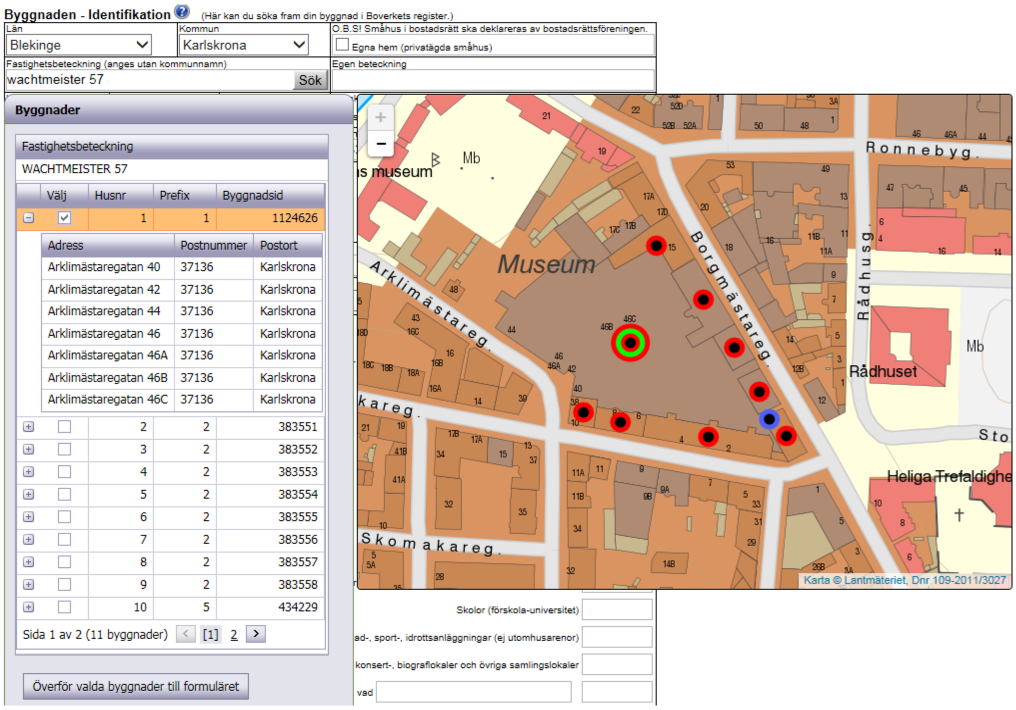
Picture 5



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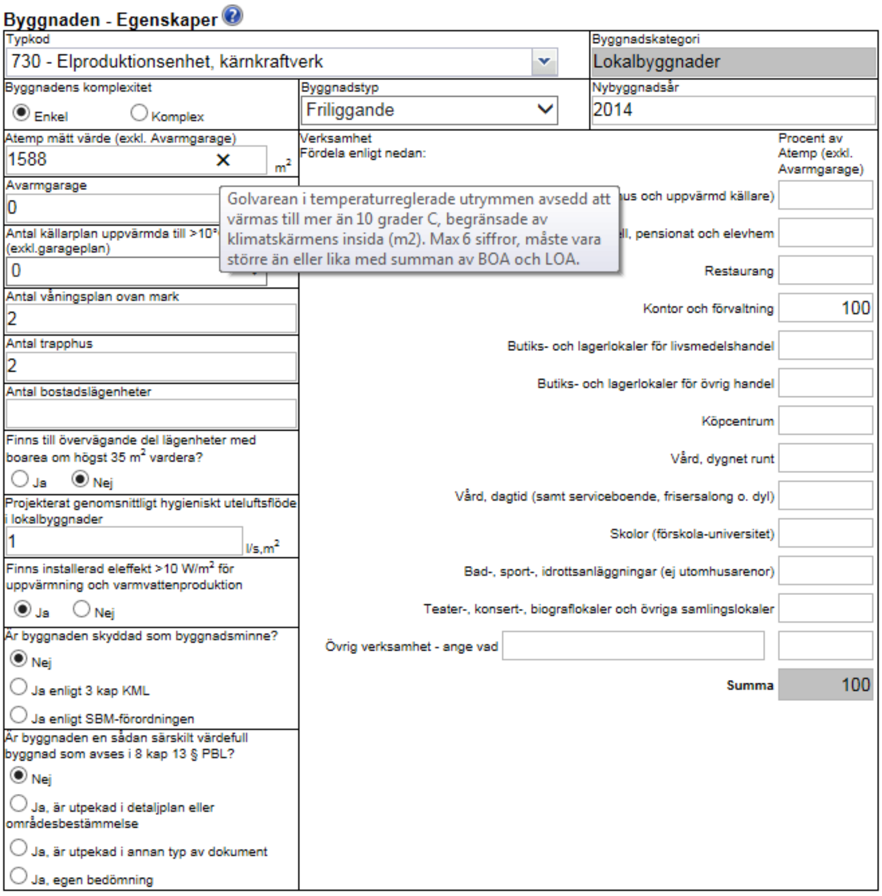
Picture 6


Byggnaden - Egenskaper

Typkod: 730 - Elproduktionsenhet, kärnkraftverk
Byggnadskategori: Lokalbyggnader
Byggnadens komplexitet: (•) Enkel ( ) Komplex
Byggnadstyp: Friliggande
Nybyggnadsår: 2014
Atemp mätt värde (exkl. Avarmgarage): 1588 m²
Avarmgarage: 0
Antal källarplan uppvärmda till >10° (exkl.garageplan): 0
Antal våningsplan ovan mark: 2
Antal trapphus: 2
Antal bostadslägenheter:
Finns till övervägande del lägenheter med boarea om högst 35 m² vardera? ( ) Ja (•) Nej
Projekterat genomsnittligt hygieniskt uteluftsflöde i lokalbyggnader: 1 l/s,m²
Finns installerad eleffekt >10 W/m² för uppvärmning och varmvattenproduktion: (•) Ja ( ) Nej
Är byggnaden skyddad som byggnadsminne? (•) Nej ( ) Ja enligt 3 kap KML ( ) Ja enligt SBM-förordningen
Är byggnaden en sådan särskilt värdefull byggnad som avses i 8 kap 13 § PBL? (•) Nej ( ) Ja, är utpekad i detaljplan eller områdesbestämmelse ( ) Ja, är utpekad i annan typ av dokument ( ) Ja, egen bedömning

Golvarean i temperaturreglerade utrymmen avsedd att värmas till mer än 10 grader C, begränsade av klimatskärmens insida (m2). Max 6 siffror, måste vara större än eller lika med summan av BOA och LOA.

Verksamhet
Fördela enligt nedan:

Verksamhet	Procent av Atemp (exkl. Avarmgarage)
...us och uppvärmd källare)	
...l, pensionat och elevhem	
Restaurang	
Kontor och förvaltning	100
Butiks- och lagerlokaler för livsmedelshandel	
Butiks- och lagerlokaler för övrig handel	
Köpcentrum	
Vård, dygnet runt	
Vård, dagtid (samt serviceboende, frisersalong o. dyl)	
Skolor (förskola-universitet)	
Bad-, sport-, idrottsanläggningar (ej utomhusarenor)	
Teater-, konsert-, biografilokaler och övriga samlingslokaler	
Övrig verksamhet - ange vad	
Summa	100

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Heating Demand Calculation of build stock based on 3D City Models using SimStadt

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Introduction

According to the Sustainable cities' report (2013), cities account for over 70% of both energy consumption and carbon emissions. An urban energy transition is thus essential to lower greenhouse gases that contribute to climate change (Van der Veken et al. 2004) and the exhaustion of energy resources (Pérez-Lombard et al. 2008).

In most European countries, cadastral databases store building information such as building footprint and usage. Such databases enable a first statistical assessment of the building energy demand based on statistical energy consumption ratio. In addition to the cadastre databases, virtual 3D City models allow to consider the real geometry of each building, including in particular their volume and façade/roof orientations. This data is a very valuable input for the calculation of individual building space heating and cooling demand, photovoltaic potential assessment and other energy-specific simulations at urban scale. Residents and urban planners could evaluate saving potentials according to different refurbishment scenarios in order to optimize the cost-benefit ratio. Estimates about solar potentials and heating/cooling demands could help citizens, urban planners and investors to contribute in the development of new energy efficient city districts.

In this paper, the urban energy simulation platform SimStadt is introduced. It enables the mass processing of large 3D city models in urban energy simulations, mainly heating and cooling demand, CO_2 emissions and PV potential analysis. The system has been evaluated and applied in the scope of the environment projection plan of the administrative district of Ludwigsburg with it 34 municipalities and a total population of over half a million inhabitants.

State of the Art

There are already some examples for the use and enrichment of 3D city models with energy-related key figures for urban energy simulation purposes. Dalla Costa et al. (2011) extended 3D building models to allow the definition of *thermal zones* for buildings, *opaque envelop elements* for boundary surfaces and *transparent envelope elements* for openings. They used the 3D model of the town of Monteveglio to come up with energy indicators like *distribution of heat losses*, *thermal consumption trend* and *domestic hot water production* at building-scale and city-scale. Their data model can be used for energy simulations and allows the representation of feature types and relationships which are important for monthly energy demand calculations. Nouvel et al (2013) performed monthly heating demand calculations on 3D city models of Ludwigsburg and Karlsruhe and considered supplementary parameters such as building physics (e.g. *window to facade ratios, U-Values)* and building usage (e.g. occupancy density, average intern gains) for their calculations. Schrenk et al. (2013) used 3D city models to compute energy balances and estimate building energy performances. They aimed at supporting planning activities at building-scale as well as city-scale. Prandi et al. (2013) performed solar irradiation calculations based on 3D city models. Kaden & Kolbe (2014) developed a system based to estimate energy demands of buildings in the city of Berlin to calculate a building energy performance label for space heating and hot water.

CityGML

The CityGML standard (Gröger et al. 2012) of the Open Geospatial Consortium is an internationally accepted model for the storage and exchange of 3D city models. In contrast to pure visualization formats such as VRML/X3D and Collada, CityGML is a feature-oriented semantically rich data model. CityGML provides schemas for topographic objects in 3D city and landscape models with respect to their geometry, topology, appearance, and attributes. CityGML represents, digital terrain models, water bodies, vegetation, transportation, and city furniture objects. The Application Domain Extension (ADE) mechanism in CityGML enables the extension and also the restriction (profile) of CityGML to domain specific applications.

The building module of CityGML supports a multi-resolution model with five discrete Levels of Detail (LoD) to represent the building geometry as shown in Figure 1. LoD 0 is similar to the 2D building footprint embedded in 3D space. In LoD 1, the building footprint is extruded to either the highest point or the average height of the roof. Metadata will be used to give an exact definition of the building height in an LoD 1 data set. LoD 2 includes the geometry of the roof and may use image textures for the building façades. From LoD 2 on, a semantic decomposition of the building into boundary surfaces such as roof-, wall-, and ground surfaces can be applied. In Lod 3, the façade of a building is modelled in more geometric detail. In addition, windows and doors become semantic elements. The interior of the building is modelled in LoD 4.

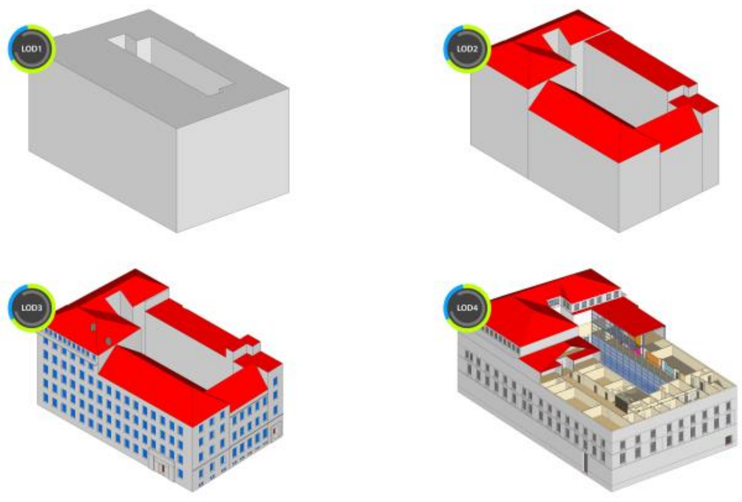

Figure 1. The Levels of Detail 1 to 4 of CityGML applied to an example building of the Stuttgart University of Applied Science

Most of the existing CityGML models consist of terrain and building data in LoD 1 and / or LoD 2, for example Stuttgart 3D, Karlsruhe 3D, Zürich 3D, and Graz (Xu 2015). Some of the 3D city models are freely available as open data (Berlin3D, Rotterdam 3D, Lyon (Plane 2015)), but most of them have to be licensed.

In Germany, mainly two types of 3D city models have to be distinguished. On municipality level, 3D city models exist for most of the larger cities. These models usually follow the SIG3D modelling guidelines for building models (SIG3D 2013), with building geometry mainly LoD 2 including some buildings in LoD 3. On state level, 3D city models are available in LoD1 and partially in LoD 2 (Oestereich und Schleyer, 2015), covering the complete building stock in Germany. These models follow the defined ADV CityGML profile (Gruber et al. 2014). This profile restricts the modelling possibilities of CityGML but enables a fully automated model generation based on aerial imagery and airborne laser scanning. On European level, a mapping to the INSPIRE 3D building model has been developed with the CityGML INSPIRE Application Domain Extension. Figure 2 illustrates the role of these slightly different data models. A detailed analysis of the data models is given in (Löwner et al (2012, 2013).

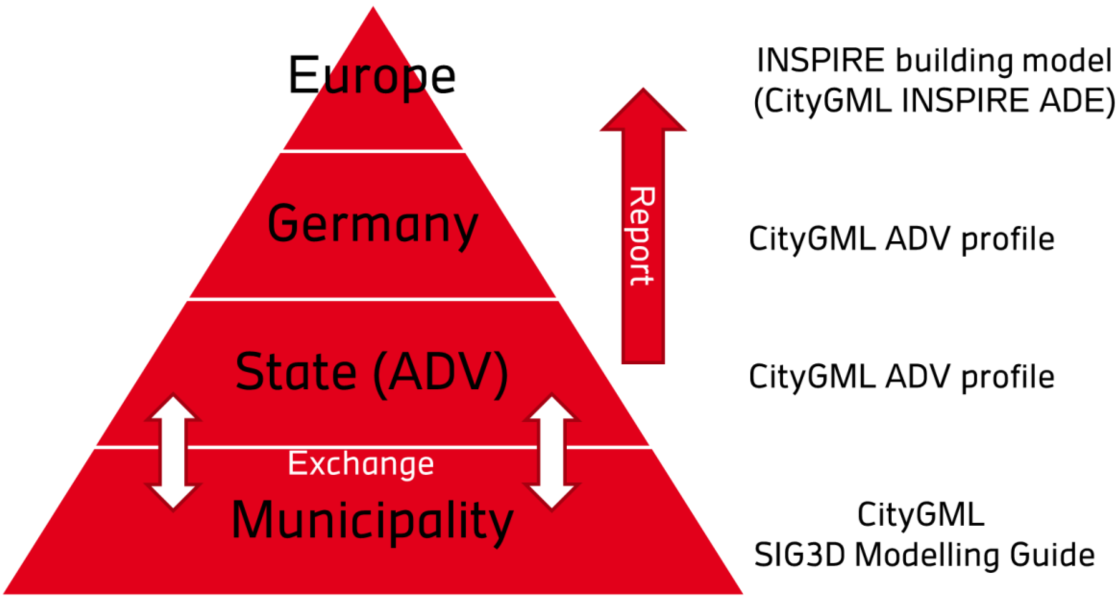

Figure 2: Data models for 3D City models based on CityGML from municipality to European level

In order to perform energy-specific calculations of 3D city models based on CityGML, not only the 3D building geometries are needed, but also additional energy-related key figures about building physics, energy systems and occupant behaviour. These figures are required for thermal modelling of the buildings and for predicting their heating demands more accurately. CityGML as of version 2.0 offers only few semantic attributes relevant for energy simulation, such as the *building function*, *year of construction*, *number of storeys* and *roof type.* Other important energy-related key figures like thermal zones, energy systems and occupant behaviour cannot be encoded. These shortcomings of the CityGML standard from the energy simulation point of view led to the development of a CityGML application domain extension (ADE) for energy-related key figures. This so called CityGML Energy ADE allows the thermal modelling of buildings required for urban scale energy simulation according to the heat demand calculation standards ISO 13790 and DIN V-18599-2 (Nouvel et al. 2015).

SimStadt Workflow for Heating Demand Calculation

SimStadt is a modular urban energy simulation system which allows the composition and execution of different urban simulation workflows corresponding to various urban energy analyses based on a CityGML model. Among those are analyses on space heating and cooling demands, photovoltaic potentials and refurbishment scenarios (SimStadt, 2013).

The system is modular in so far, that every simulation workflow is a sequence of exchangeable workflow steps. Each workflow step performs a defined action and takes a defined set of simulation parameters. The computed results of each workflow step are passed on to subsequent steps. In the following an overview of the SimStadt's DIN V-18599 compliant monthly heating balance workflow is given. Figure 3 shows the user interface for this SimStadt workflow.

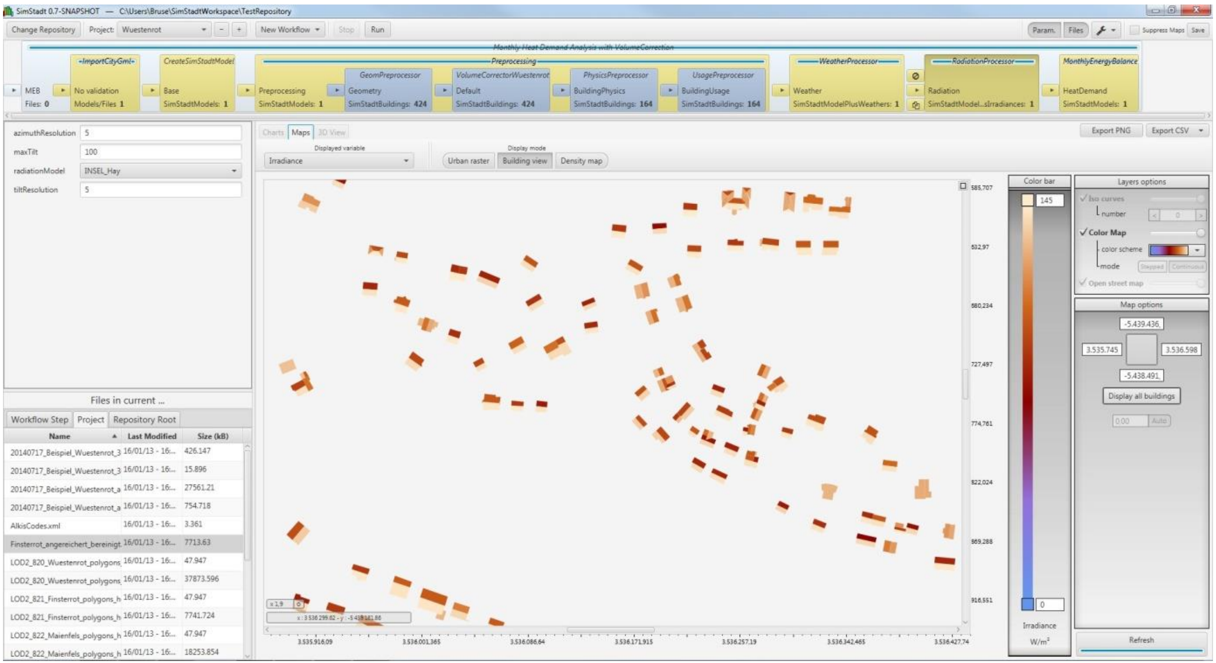

Figure 3: SimStadt Workflow for space heating demand. The figure shows the radiation processor.

The presented approach is based on the heating demand calculation method described in the German norm DIN V-18599 (based on the same methodology than the European norm ISO 13790). Before we describe the approach in detail, the calculation method is outlined in the following sections.

The norm DIN V-18599-2 describes the heating demand calculation of buildings considering the heating energy balance inside building thermal envelope. In this balance, the following heat sources and heat sinks are considered on a monthly basis: transmission heat sinks, ventilation heat sinks, internal heat sources (occupants, electric appliances, e.g.), heat sinks for irradiation losses and heat sources due to solar insolation.

The monthly energy balance method is basically a static energy calculation method. However, the heat capacity of a building is considered for the calculation of the average building time constant. This time constant and the resulting utilization factor allows for consideration of the simultaneity effect between heat sinks and heat sources in the monthly energy balance.

This method has input data requirements which can partly be satisfied through the 3D city model itself, through benchmarking values or standard values (e.g. European Building Typology Tabula (TABULA, 2015), Standard usage data from the DIN V-18599-10):

- Geometric data: building volume, areas and orientation of outer- and shared walls, roofs and basement.
- Building physics data: Heat transfer coefficients (U-values) of the different components, total energy transmittance (G-value) of the transparent components, total heat capacity, infiltration rate and thermal bridge factor of the building.
- Building usage data: Density of occupation and resulting internal gains, schedules for heating and ventilation (times of reduced operation mode, set-point temperatures and air change rates).

Monthly weather data: local monthly ambient and sky temperatures together with insolation per orientation. This data is not part of the building model, but necessary to calculate the heating demand of the buildings in a given climate and location.

For the assessment of the building energy performance the calculated heating demand is generally normalized over the heated area like in the Energy Performance Certificate.

Use Case: Administrative district of Ludwigsburg

The administrative district of Ludwigsburg is located in the center of the state of Baden-Württemberg in Southwestern Germany. The district has an area of 687 km^2 and a total population of 517.000 civilians. The whole study area includes 34 municipalities in the administrative district of Ludwigsburg. The city of Ludwigsburg was not part of this study, but the same methodology was applied to the city of Ludwigsburg already in 2014 (Nouvel et al. 2014).

An Energy action plan was conducted to identify and plan CO_2 emission savings, based on a CityGML LoD 2 model. The data includes about 100.000 building models, with total data size on disk amounts 2.4 GB. The terrain tiles count 1554 with size on disk about 43.5 GB. Each tile has a resolution of 1 x 1 m and covers a ground area of 1 km^2. The orthophotos count also 1554 (one for each terrain tile) with total size on disk of 77.4 GB. The ground resolution of the orthophotos is of 0.25 m. The orthophotos and terrain data are used for visualization purposes only.

The building models are used in different workflows of the urban energy simulation platform SimStadt to assess the actual space heating demand and the related CO_2 emissions per building, predict energy savings potential following different refurbishment scenarios, and identify the solar energy potential.

For the whole studied area, the total yearly heating demand reaches 3.9 TWh, with an average specific heating demand of 145 $kWh/m^2.yr$. Considering the heating system distribution available for each municipality (from census data survey), this corresponds to 0.92 Megatonnes equivalent CO_2 per year.

For the photovoltaic potential analysis, only roofs with a surface larger than 40 m^2 and receiving more than 1100 $kWh/m^2.yr$ solar radiation have been selected. In total, the diffuse power central formed by all these roofs could generate 668 MWh/yr, which would cover 26% of the electric demand (for building electrical appliances) of the administrative district.

Figure 4 shows the specific space heating demand per building in a 3D visualization. The visualization is done using X3D which enables a web-based access using X3DOM (Athanasios and Coors, 2015).

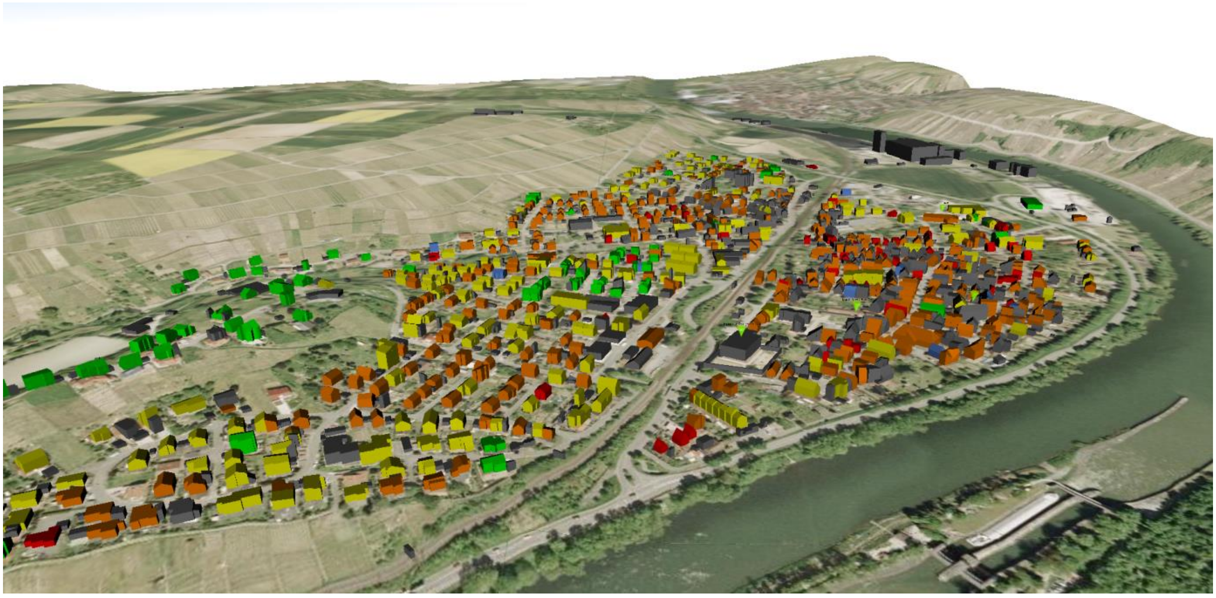

Figure 4: Specific heating demand per building calculated with SimStadt.

Conclusion and Perspectives

In the recent years, considerable progresses have been realized in both domains urban energy simulation and 3D Geographical Information System, however without notable cross-domain interactions. The new urban energy simulation platform SimStadt combines both domains. The current version integrates workflows, which allow for first city-scale energy demand diagnoses as well as low-carbon scenario simulations. The definition of a workflow to calculate energy performance labels per building on regional and national level is feasible. Meanwhile, it remains a great deal of work to model energy flows more precisely, with higher Level of Details, shorter time resolutions (typically hourly loads) and taking into account the whole complexity of urban scale interactions. In any case, based on its extensible modular structure and on the full potential of virtual city models, the new SimStadt platform may provide an adequate and powerful solution to plan and coordinate the energy transition, at the scale of neighbourhoods, cities or whole regions.

Acknowledgement

The terrain data and the orthophotos were provided by the District Office of Ludwigsburg. The CityGML data were provided by the Department of Geoinformation and Land Development Baden-Württemberg (LGL | Landesamt für Geoinformation und Landentwicklung). The contracting entity of the project "Integrated Climate Protection Concept for the district of Ludwigsburg" is the Department 21 of the district Ludwigsburg. The concept is developed by a consortium headed by Drees & Sommer. The funding of the SimStadt project by the Federal Ministry for Economic Affairs and Energy is gratefully acknowledged.

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ZEROcarbon Roadmap2020

Sonderborg - a Bright Green Danish Municipality

Roadmap for creating green growth and a ZEROcarbon Sonderborg

Bright Green Business
ProjectZero

The ProjectZero Road to Zero 2020

Sonderborg is a Danish Municipality beautifully located near the Baltic Sea in Southern Denmark. We are 300 km drive from Copenhagen, and 200 km drive from Hamburg Germany. Sonderborg has a population of 76,000 people, of which 27,000 people live in the Sonderborg city area. The 850 year old Sonderborg castle and the Battlefields of Dybbøl (1864) showcase Sonderborg's rich cultural heritage together with a vibrant modern community.
We focus on good education, culture, living and business. Sonderborg is home for leading global tech companies like Danfoss and Linak.

What we want

Sonderborg aims to be a ZEROcarbon growth area 20 years ahead of Denmark. ZEROcarbon means phasing out all energy-related carbon-emissions.
ProjectZero is the vision for making Sonderborg ZERO-carbon by 2029, creating sustainable growth and new green jobs along the road - based on ambitious carbon reduction goals and new Bright Green Business solutions. Our vision is a powerful innovation engine for new solutions and business concepts. The innovation engine will show the future use of energy, food, water and other resources.

What we do

We strive to create market-driven concepts benefitting citizens and businesses. We do this by developing new solutions and collaborative partnerships based on smart climate solutions.

What we aim at achieving

In 2007, the City Council of Sonderborg adopted the vision of becoming ZEROcarbon. Since then, approximately 800 new green jobs have been created. By 2014, the Sonderborg-area has reduced its CO_2 emission by 30%, well beyond the first sub-goal of 25% emission reduction by 2015. The next sub-goal is to achieve a 50% reduction by 2020 (compared to the 2007-baseline). This will create almost 1000 new jobs, and the perspective of becoming ZEROcarbon by 2029.

A robust open platform for participation

Roadmap2020 is built on ProjectZero's past years of experience from Roadmap2015 and the Masterplan2029, which provide the overall framework for the creation of the ZEROcarbon Sonderborg by 2029. Roadmap2020 outlines our plan to meet the next set of goals.

www.projectzero.dk

We achieve our goals!

In Sonderborg we think big and act.

We are driven by enthusiasm - new technology and science can be used to create a better life. Within that principle, a major part of our business is developing new technological solutions to save power, for which the whole world desires.

Many people travel vast distances to visit Sonderborg to see how our citizens, institutions and businesses jointly transform the area to a sustainable CO_2 neutral future. ProjectZero's Roadmap2020 is an important milestone on the road to becoming ZEROcarbon by 2029.

The challenges are significant, but together we will show that it´s possible to solve them.

We have a strong local interest in climate and energy. Our desire is to do more to identify and develop the solutions that are necessary to achieve the 2020 goal. Several of the factors that will be decisive to a continued success are yet unknown. It is not yet possible to draw the complete roadmap towards the year 2020.

However, through active participation of approximately 100 local citizens and national experts, we have succeeded to create specific proposals for future solutions and business concepts. These concepts outline how the climate challenges of tomorrow can be solved.

Our concept opens new opportunities for market-based energy and climate solutions though new partnerships. This creates business and jobs while reducing CO_2 emissions. The concepts do not always represent the entire solution, but they are facilitators for "Sonderborg's Great Transition".

Sonderborg´s Great Transition is a story about solutions and determination created through commitment, collaboration and networking across industries and civil society. It is the story of how we develop green lifestyles for ourselves and the next generations. Our children are given a tailored curriculum from kindergarten onward. They are taught how to live in a sustainable, innovative and interconnected world. These values also characterize the everyday life of our university and international businesses and thereby also support the Bright Green Business creation.

It is now up to all of us: citizens, businesses, organizations, educational institutions, utility companies and our municipality to jointly implement the next exiting phase of the ProjectZero vision.

Peter Mads Clausen
Chairman of The ProjectZero Foundation (2007-2014)
Chairman of The Danfoss Foundation

How to use Roadmap2020: Focus on green growth and job creation

ProjectZero is the vision of creating economic growth and new jobs in Sonderborg, transitioning to a ZEROcarbon society. This is what we call “The Great Transition”. By 2020, a 50% CO_2 reduction is expected to be achieved. The ProjectZero vision is a demonstration for Denmark and the rest of the world on how CO_2 reductions and growth go hand in hand.

Roadmap2020 is a specific proposal for how the Sonderborg area can achieve its ambitious 2020 goal through market-based partnerships that accelerate the transition and kick-start new development projects.

Roadmap2020 consist of “SixBigConcepts.” Three focus segments are based on the Roadmap2015 learning: Community & Citizens, Business and the Public Sector. Each of the focus segment programs have been reviewed and fine-tuned to maximize impact based on value creation, networks and cross-sector synergies for the Roadmap2020.

Three Focus Sectors
Community & Citizens: Educating and engaging the citizens based on value and benefit creation. Specific programs include ZEROhome, ZEROdrivers license and House of Science.

Businesses: Partnering with business to develop and share best practices to save energy and reduce carbon-footprint. Specific programs include ZERO+Business, ZEROshop and financial optimization.

Public Sector: Create policies and funds to reduce the public sectors carbon footprint by energy retrofitting public buildings and schools in cooperation with utility companies.

Roadmap2020 also describes three new specific business-oriented Development Themes, to be incorporated by private and public stakeholders assisted by the ProjectZero Company: SmartGrid, Bio-Economy and Green Transportation.

Three new Development Themes
SmartGrid: The joint regional development of a Smart Grid phasing-in more renewable energy e.g. solar and wind.

Bio-Economy: Active involvement of businesses that use biomass resources in production of food, energy, bio-based products and the establishment of new bio-energy production facilities in the Sonderborg area.

Green Transportation: Develop coherent solutions and concepts for green transportation in urban and rural areas.

For the SixBigConcepts to work, it requires commitment and active stakeholder participation within and outside the Sonderborg area. Therefore, Roadmap2020 is an open platform for all interested stakeholders to participate and benefit from. Bright Green Business and learning potential will occur from growth as a result of new partnerships, technology development and implementation towards 2020.

The following pages will describe each of the SixBigConcepts by outlining the goals, challenges, best practice examples and specific tasks to come.

Peter Rathje
CEO, ProjectZero Company

The vision:
A Green Growth Engine for Sonderborg

The SixBigConcepts
Since its creation in 2007, the ProjectZero vision has inspired citizens and businesses to implement green initiatives. An impact analysis conducted by NIRAS (an independent Danish consulting engineering company) of the impact on job creation and investment concluded in 2013 that implementing the ProjectZero vision has created about 800 new green jobs since 2007.

The implementation of Roadmap2020 is projected to create additional 900 new green jobs annually. Almost 80% of the new jobs will be created in Sonderborg and Southern Jutland. Large capital investments are expected in tandem.

From 2015 onward, it is expected that the Sonderborg areas' green transition will "attract" 700 million DKK (129.6 million USD) in capital investments per annum.

Local businesses are expected to contribute with about 200 million DKK (37.0 million USD) every year as well.

The analysis shows that regional, sub-regional and cross-border projects and cooperation have a great additional potential for job creation in Sonderborg.

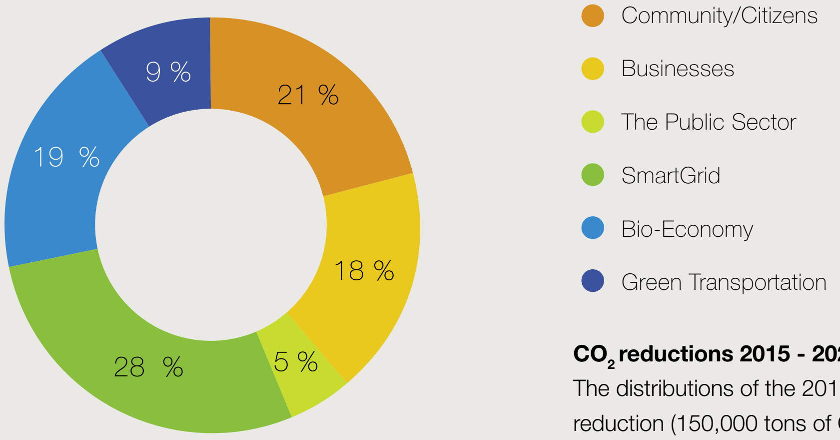
Additional growth potential will be generated by export of Bright Green Business solutions, international business participation in new demonstration projects, visitors spending and the enhanced global branding and marketing of ProjectZero's efforts.

The vast majority of the new jobs (42%) will be created within the building and construction sector, due to the expected investments in new energy-efficient solutions by homeowners and citizens.

In the coming years, the Sonderborg area expects to install large costal wind turbine project and a new bio-refinery. The related job creation has not been calculated because the exact implementation of these projects are not yet clear. Due to similar uncertainties, the jobs created by Sonderborg's Bright Green Business solution companies is not included in our economic projections.

	Annual job creation	Accumulated jobs
Sonderborg Municipality	490	2456
Remaining part of Southern Jutland	276	1379
Remaining part of Southern Denmark	67	335
Greater Denmark	154	771
Total	987	4941

The total estimated direct and indirect impact on employment as a result of the implementation of Roadmap2020. The indirect employment impact is only calculated for the Municipality of Sonderborg. Accumulated figures cover the accumulated job creation during 2015 - 2020.

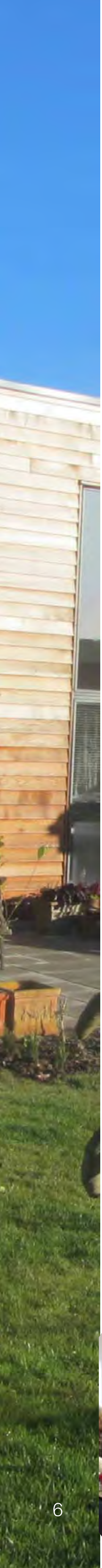


The SixBigConcepts Carbon reductions

CO_2 reductions 2015 - 2020
The distributions of the 2015-2020 accumulated carbon reduction (150,000 tons of CO_2) in per cent of the total reduction

Focus segment

Community & Citizens



Goals

Community and citizens are important resources in the transition and will continue to be challenged by improving energy efficiency. Not only heating in their homes, lighting and appliances, but also awareness of the use and sources of energy.

During 2015 to 2020 the focus segment of Community & Citizens must reduce their CO_2 emissions by more than 33,700 tons. This corresponds to 21% of the total Roadmap2020 reduction.

Challenges

New programs and initiatives shall be driven by business, based on new cross sector partnerships to offer the community and citizens the best possible private energy solutions.

Attractive solutions for energy-efficient renovations must be available and easily understood by all citizens.

Better and more attractive financing options must be secured to motivate citizens to make the necessary investments.

Local craftsmen must take a lead in providing the citizens with information and guidance on energy renovations.

The good examples

Since 2010 ProjectZero has created the ZEROhome program to engage homeowners to energy retrofit their buildings/homes. Over 1,100 private homeowners in Sonderborg have been visited by trained ZEROhome energy advisors to improve awareness about options and motivation to act. At the same time, the ZEROconstruction program has trained 65% of the area's craftsmen in state of the art energy consulting and -solutions.

The program support have enabled over 600 homeowners to invest an average of 155,000 DKK (28,700 USD) in mainly building improvements. The average household saved 5,800 MWh. The savings are equivalent to 2,000 tons of CO_2 per-annum for the entire Sonderborg area. The total investments by private home-owners equivalent to 105 million DKK (19.4 million USD) since 2010.

The specific tasks

We will continue to facilitate the training of efficient and dedicated energy advisors in the construction industry to ensure that home owners have the best information, guidance and confidence in the transition. In order to speed up the transition of the public housing sector, a new innovative cooperation between Sonderborg`s seven housing associations and their residents will be established.

Key players

- The ZEROconstruction program and EUC Syd (technical college and vocational training school) train craftsmen as energy advisors
- The housing associations of Sonderborg in a project cooperation with EUC Syd and contracting company Jorton
- The private rental housing owners
- The citizens of Sonderborg

New participation methods will be developed for the transition in the private rental buildings sector.
In order to promote energy renovation of the housing stock, new concepts and cooperation with partners will be developed. Specifically, cooperation and solutions with local craftsmen must be developed to accelerate the shift of heating sources to renewables.

Impact and value creation

We will get an energy-optimized housing stock across all housing sectors. The stock will be better prepared to meet the future Nearly Zero Energy Buildings Directive, promulgating that the European housing stock to use 90% less energy by 2050.

Less energy consumption improves the building's energy label, lowers the energy cost and improves the building's sales price, when the building is offered for sale.

The initiatives also ensures further job creation and growth in the construction industry.

Did you know…

- There are 18,600 private homes in Sonderborg, averaging 65 years of age?
- That approximately 94% of Sonderborg`s houses have an energy label of "D" or less?
- From 2016, it is not permitted for the homeowners to replace an old oil burner with a new one, if they are able to connect to district heating?
- That EU strong policy ambitions for energy-retrofitting all buildings so that energy consumption in buildings/homes by 2050 will be reduced by 90% ?

Focus segment

Businesses

Goals

Sonderborg's manufacturing, trade, agriculture and construction industries must reduce their CO_2 emissions by another 28,000 tons before 2020. This corresponds to 18% of Sonderborg's total CO_2-emmission reduction from 2015 to 2020.

All local companies must be aware of opportunities and motivated to participate and contribute.

The majority of the companies must commit to specific initiatives in order to reduce their energy consumption.

Accelerate green growth further through scaling up Bright Green Business solutions developed by Sonderborg's leading technology companies.

Challenges

The financial crisis caused a decrease in economic activity, which also decreased CO_2 emissions. As the economic recovery commences, companies will have to work hard to maintain and improve the post-financial crisis levels of CO_2 emissions. The economic recovery must be CO_2 neutral.

Analysis shows that our companies normally invest in projects with a payback period of four years maximum. This is challenging as many investments in CO_2 reduction and energy savings take longer to accumulate gains. This will continue to be a major sticking point for many companies.

The good examples

ProjectZero has developed a business concept called ZERO+Business. It consist of two programs: the ZERO-company and the ZEROshop program.

The ZEROcompany program trains companies in the most effective practices to reduce energy consumption and CO_2 emissions while maintaining or improving competitiveness in the market. 45 local companies are committed to the ZEROcompany program, reducing their carbon footprint from 10 to 45%.

Several of these companies have specifically developed products and services offering climate and energy saving solutions to all kind of applications – what we call Bright Green Business.

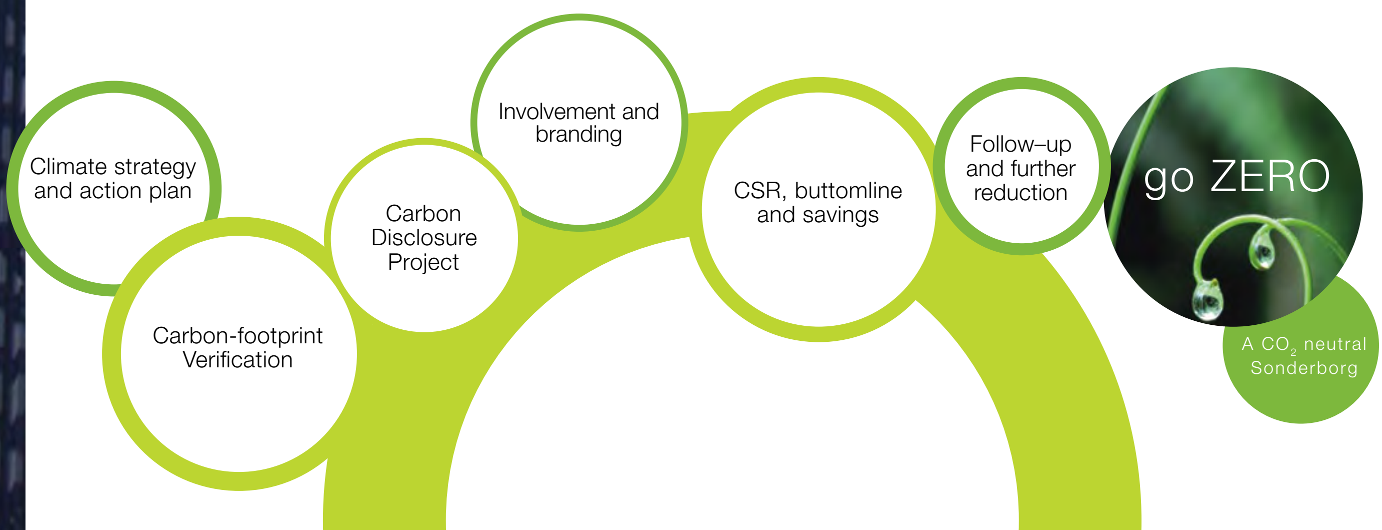
The ZEROshop program enables storefront retailers to save energy and lower carbon emissions on site or in their supply chain. Almost 100 of Sonderborg´s shops and small business have committed to the ZEROshop program. They have received a free energy screening by ProjectZero or local electrician companies, which has helped them to reduce their CO_2 emission from 10 to 45%.

The specific tasks

Sonderborg areas' Corporate Social Reasonability (CSR) culture must become more cooperative in finding joint solutions to reduce CO_2 emissions while growing and creating green jobs.

Key players

- Businesses, shops, energy companies, consultants and solution providers
- Electrician companies are trained as energy advisors and assist shops to achieve further carbon reductions



ProjectZero and partners will facilitate a best practice business solutions knowledge base to be shared. This will enable businesses to develop ambitious carbon footprint reductions strategies, improve their bottom line and strengthen their CSR-activities. These synergies go hand in hand with the implementation of Roadmap2020.

Value and impact

The ZERO+Business concept does more than facilitate a better bottom line and improve the environment: participating firms in ZEROcompany and ZEROshop demonstrate strong corporate social responsibility values. This is key to build a strong loyal community relationships and develop new Bright Green Business markets.

By executing the ZERO+Business concept another 250 jobs are annually expected to be created within the Businesses focus segment.

The successful creation of new Bright Green Business solutions will be based on businesses' core competencies, lessons learned in Sonderborg's demonstration lab and scaling-up opportunities abroad.

Did you know...

- Global technology leaders like LINAK, OJ Electronics and Danfoss have their corporate headquarters in Sonderborg
- LINAK is a company that is pioneering the actuator market within healthcare, office, energy and home-based lifting applications. Linak employs people in 26 countries. LINAK aims to become CO_2 neutral by improving energy efficiency and using energy from local renewables
- OJ Electronics is a leading manufacturer of floor heating control systems. OJ Electronics has developed a corporate climate and energy policy which has resulted in a 46% CO_2 reduction from 2011 to 2013.
- Danfoss is a global energy and climate technology leader, with operations in more than 100 countries and with more than 24,000 employees
- The businesses in the Sonderborg- area accounted for 39% of the area's CO_2 emission by 2011
- There are approximately 300 agriculture farms in Sonderborg

ZERO company

Committet to a carbon neutral Sonderborg

Focus segment

The Public Sector

Goals

The public sector must reduce its CO_2 emission by 8,000 tons by 2020. That is twice the expected reduction by 2015. The reduction must primarily come from heating, lighting and appliances.

Challenges

From 2007-2011 the public sector was unable to curb CO2 emissions, despite several good cases and ambitions. We need a strong commitment to achieve Sonderborg's 2020 goal.

The good examples

The Municipality of Sonderborg has shown a strong commitment to achieving a 25% CO_2 reduction within its own operation. Such initiatives include the monitoring of general operational energy use, retrofitting of municipal buildings and schools and facilitating green learning and education.

Sønderborg Forsyning is Sonderborg's public water, energy and waste utility company. The utility company has initiated a plan to transition into CO_2 neutral operations by:

- Bio-gas generator using sewage
- Efficient sorting of household waste by citizens,
- Mounting 1,300 m^2 of solar panels on its administration buildings
- Adding SmartGrid management solutions to its thousands of water pumps

The area's schools have created a "green thread" in the school curriculum from kindergarten to Ph.D courses. They are based on climate, innovation and sustainability. The City Council supports the green curriculum that started in the school year 2013/14.

The municipality's school administration has collaborated with the (private non-profit) School of Production and the EUC Syd (the technical college and vocational training school) to retrofit school buildings and construct new to be more energy efficient.

This demonstrates environmental sustainability in the actually learning environment. This shows our youth we are serious about climate change and encourages their commitment, participation and support in the future.

The specific tasks

The ZEROcity business concept will enable Sonderborg as an entire community to become a best practice model, demonstrating the newest energy and climate solutions used for the green transition.

Collaboration across sectors and stakeholders are key to success. The transition will include new innovative financing instruments and solutions. Increased focus on Bright Green Business with global scaling will accelerate the value creation to participating stakeholders and consolidate "Sonderborg's Great Transition".

The professionalization of new "green business tourism" initiatives with efficient and effective service and follow up on visiting guests will increase the awareness of ProjectZero. Supporting educational learning and consulting must be strengthened to inspire cities all over the world to get started and achieve ambitious ZEROcarbon goals.

Establishment of strong stakeholder partnerships across the municipality who can challenge the current thought paradigm will be required. Sonderborg must actively engage in regional networks both north and south of the border to create a larger market for green business development and to impact regional thinking and policies.

Did you know…

- Sonderborg is visited weekly by delegations from abroad who seek inspiration for own local carbon reduction initiatives
- Sonderborg accounted for 29 out of 35 green transition/ sustainability projects in Southern Jutland in a national promotion project featured by Danish National Television in 2013. www.voresomstilling.dk

Value and impact

8,000 tons of CO_2 can be saved for the benefit of the climate while taxpayers save operating costs.

The “Bright Green Business” solutions and knowledge is scalable and has large global market potentials. Cities act while nations talk and cities represent a new growing buying group for the business segment.

Businesses and citizens have new competencies and embrace new sustainable behavior necessary for a sustainable transition of our cities.

Key players

- The Municipality of Sonderborg (as company and local authority) and utility company “Sønderborg Forsyning” with its ambitions to become a first mover in implementing SmartGrid solutions
- The Public-Private Partnerships behind ProjectZero in cooperation with firms, utility companies, universities and other institutions from all over the world that will assist creating a full-scale transition - based on what cities can achieve
- Sonderborg´s learning and educational institutions
- Citizens and businesses’ of Sonderborg

Luftfoto Syd

Development Theme

A Smart Grid

Goals

The ambition of the Smart Grid Development Theme is to develop and demonstrate the future integrated SmartGrid solution at city-level in Sonderborg. The goal is to develop a full scale demonstration that strategically connects the energy demand and supply, based on electricity as leading future energy source, combined with green district heating and green gas from renewable sources.

On the supply side, Sonderborg´s renewable energy production capacity must be expanded with 25 MW through a combination from 15 MW wind and 10 MW of solar energy output by 2020.

Demonstration and development projects must promote the integration of renewable energy into a “SmartGrid” demonstration area. The first demonstration and development project of this kind is ZERO-GI.

The continued expansion of Sonderborg’s district heating networks must be coordinated and supported. This will ensure a stronger utilization of the established renewable energy production facilities.

From 2015 to 2020, the SmartGrid initiatives are expected to reduce Sonderborg’s CO_2 emissions by at least 43,000 tons. This is equivalent to 28% of the total scheduled reductions during 2015-2020.

Challenges

Securing a strong community support to the establishment of large renewable installation facilities, such as wind farms.
Securing value creation for all parties involved in the expansion of renewable energy capacity and within the SmartGrid projects.
Managing changing frames and policy conditions provided at national and EU-level.

The good examples

Sønderborg Fjernvarme (district heating company) has established Denmark’s first commercial geothermal hot water plant and is one of the greenest district heating producers in the country based on multiple renewable resources. Gråsten Fjernvarme follows the same model transitioning from fossil fuel to solar heat and biomass - and was 2015 nominated as Sustania100 candidate.

Sønderborg Fjernvarme has increased its impact from 34% (in 2013) to cover more than 43% of Sonderborg´s total heating demand. The wind energy capacity has been increased by 50% and the solar capacity doubled within two years.

Several SmartGrid-related projects have been initiated.

The company GODevelopment is creating a new innovative energy storage system. The GOD-solution accumulates electricity from wind in a high-pressure pumped water-based system. Enabling surplus of electricity from wind to be stored and turned back to electricity when required by the SmartGrid.

Future surplus of wind energy will also be accumulated as hot water in Sonderborg`s district heating networks. Augustenborg Fjernvarme has installed an electric boiler and Broager Fjernvarme plans to install a large electric heat pump to produce heat from green electricity when the energy system is overloaded with wind energy.

25 smart heat-pumps have been installed in private homes. They save money for the homeowners by accumulating heat in the buildings when energy prices are low and gather data for future development of new SmartGrid home-solutions.

Key players

Wind Power Capacity: citizens (future neighbors), landowners (investors and hosts), energy companies (investors and distributors), the Municipality and the City Council (authority and a frame setting), university scientists and NGO`s like the Danish Society of Nature Conservation.

Photovoltaic Capacity: house associations, the Municipality, farmers, local technology suppliers and SE

ZERO-GI: the Danfoss Company, SE, CLEAN Cluster, district heating companies, A/C-service companies and supermarkets.

The specific tasks

Sonderborg must establish an additional 15 MW from inland wind turbines in Sonderborg before the end of 2020 by initiating part of Sonderborg`s municipal "Theme Plan for Wind Turbines". The establishment must cooperate with all stakeholders and maintain high local ownership.

Implement targeted campaigns to ensure continued expansion of Sonderborg`s total installed photovoltaic (PV) solar capacity. This will be based on a collaboration with the area's PV-stakeholders and include house associations, farmers, the municipality (as building owner and as authority), local technology suppliers and SE.

Develop and establish a ZERO-GI supermarket demonstration plant in Sonderborg and pursue other SmartGrid opportunities in partnerships between relevant stakeholders.

Value and impact

A dynamic and SmartGrid-based energy system is key to achieving both national and international targets phasing-out fossil fuels and phasing-in energy from wind and other renewable sources. And it adds economic growth and job creation at local, regional and national levels.

Expanding the production of renewable energy creates value for local investors and new green jobs during the implementation phase.

Sonderborg becomes increasingly self-supporting with renewable energy.

Did you know...

- Sønderborg Fjernvarme and Gråsten Fjernvarme supply the citizens and companies with district heating based on almost 100% renewable energy sources
- The world´s first intelligent heat pump was installed by a Sonderborg citizen Christel Juhl Thomsen in Høruphav in 2010
- During 2013, almost 9 MW out of Sonderborg´s 2015 goal of 10 MW of Photo Voltaic was installed. During 2014-15 additional 9 MW PV capacity has been added

ZERO-GI is a play of words: synergy and exergy (energy quality and availability). The ZERO-GI concept aims to use excess heat and overcapacity in cooling systems (e.g. from supermarkets) to deliver heat into the district heating system in an intelligent and dynamic way.

Glossary:

PV (Photo Voltaic) is a term for a solar cell-based technology that produces electricity from solar radiation.

RE (Renewable Energy) is a generic term for energy based on sustainable energy sources such as wind, sun, geothermal etc.

Development Theme

Bio-Economy

Goals

Towards 2020, Sonderborg aim at transitioning into a national demonstration area for a sustainable manufacture of biomass based products.

New sustainable concepts and systems shall be developed and tested based on local resources and generating economic growth and new jobs.

Strong local demand for locally-produced bio-energy shall contribute to phasing out the local use of fossil fuels.

During 2015-2020, the Bio-Economy Development Theme is expected to reduce Sonderborg's CO_2 emissions by more than 30,500 tons, equivalent to 19% of the total expected reduction during the same timeline.

Challenges

The competing demand for biomass from food, materials and energy manufacturing is a challenge for rethinking the future use of resources.

There is still uncertainty regarding which technology solutions will become profitable standards in Denmark and abroad.

Win-win-win - all value chain stakeholders must see a profitable business and have incentives to participate actively in the transition as suppliers, manufacturers and consumers.

It is challenging to secure financing to develop scale production of bio-based materials.

The good examples

Sonderborg's district heating plants have almost phased out fossil fuels and instead undertaken extensive use of bio-mass to produce heat for buildings. The plants in Sonderborg, Gråsten and Vollerup turn waste, wood chips, wood pellets, straw and bio-oil into heat. District heating has created an increased local demand for bio-mass. The use of bio-mass has become an important step towards a 100% CO_2 neutral heating.

Sonderborg already has three bio-gas plants: Clausen Biogas at Nord-Als (manure-, biomass- based), the Sonderborg Sewage Treatment Plant (sewage sludge from waste-water treatment-based) and at Skodsbøl Deponi (waste-based).

In collaboration with the Municipality of Sonderborg, the Sønderborg Forsyning, LandboSyd (farmers association) and ProjectZero have surveyed the biomass-potentials of the Sonderborg-area and concluded that Sonderborg has great potentials for exploring the Bio-Economy opportunities.

Sønderborg Forsyning is a partner in an unprecedented initiative to collect and use the area's organic household waste for new biomass facilities.
Since March 2012, the sewage treatment plant in Sonderborg has been CO_2 neutral. The facility uses sewage sludge to produce biogas, which is converted into electricity and heating.

The specific tasks

Roadmap2020 recommends an integrated three-pronged approach to a future sustainable use of the Sonderborg area's biomass resources:

Establishment of a bio-gas plant that will produce 10 million Normal Cubic Meters of gas. This shall be based on a combination of livestock manure and bio-mass waste from other local sources.

A "Waste-to-value" demonstration project turning food waste and other residual biomass into high-value products such as proteins and fertilizers. Residual waste is utilized at the biogas plant.

Establishing a bio-refinery in the Sonderborg-area, alternatively make use of Sonderborg´s biomass in a new joint regional solution.

Value and impact

Biomass contributes significantly to a future fossil-free society.

The development of bio-economic solutions and systems has a considerable export potential and can potentially create a significant number of local jobs.

The use of bio-fuel and biogas will support a green transition within the transport sector.

Companies and public institutions can strengthen their green profiles by switching to bio-energy based products and services.

Key players

- Biomass suppliers, owners, manufacturers, farmers, Sønderborg Forsyning, local food manufacturers etc.
- The Municipality of Sonderborg (as authority, facilitator and consumer)
- Energy companies and operators (SE, DONG Energy, NGF Nature, E.ON and others)
- End users (businesses, energy producers, citizens, the transport sector)

Did you know...

- More than 700,000 tons of manure are produced per year in the Sonderborg-area - mainly from pig-farming
- Biomass and wind energy are the two main pillars of Denmark's future energy system
- Proteins, food ingredients and phosphorus can be extracted from food waste, green residuals and process waste from the food industry

Development Theme

Green Transportation

Goals

Sonderborg is a pioneer in implementing green transportation solutions and today the Municipality of Sonderborg enjoys both the status of being Denmark`s first "Green Transportation Municipality" and the "bike-municipality of Southern Denmark". But transitioning to Green Transportation requires also new thinking, policies, planning and more action.

From 2015 to 2020, the Green Transportation Development Theme initiatives are expected to reduce Sonderborg's CO_2 emission by more than 15,000 tons. This accounts for 9% of the total scheduled reductions during the same timeline.

Challenges

Economic gains of transitioning to green methods of transportation.

Changing behavior and attitudes.

Lack of user familiarity with alternative green transportation means.

The good examples

70 Sonderborg families have participated in the "Test an Electric Car" program.

Since 2009, the Municipality of Sonderborg has been certified as a Green Transportation Municipality.

Post Danmark (Danish Mail) and the Municipality of Sonderborg use electric bicycles and electric vehicles. Danfoss, SE, Sonderborg Forsyning among other companies have also integrated electric vehicles in their operations.

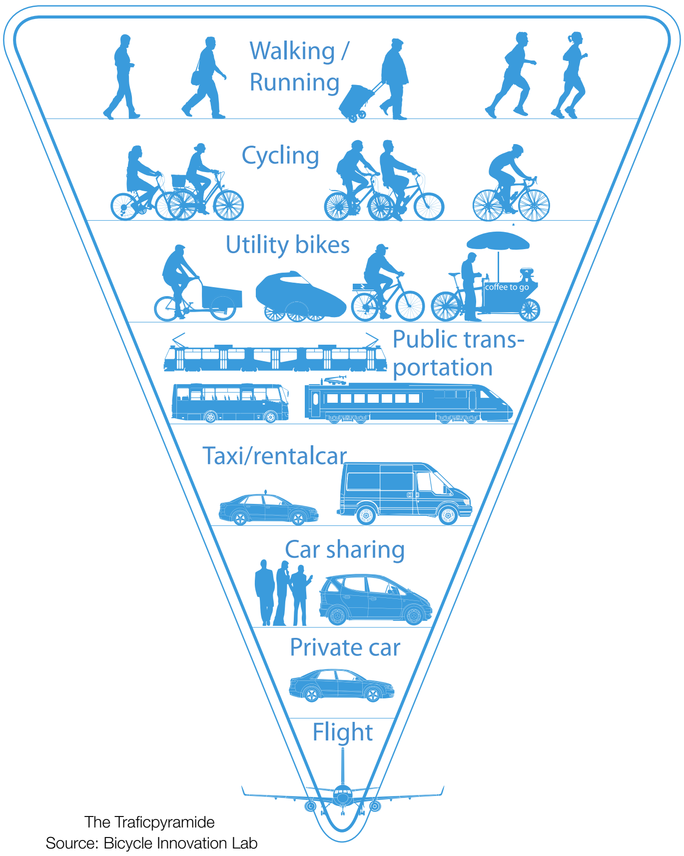
The specific tasks

Towards the year 2020, it is important to change citizen' attitudes on Green Transportation options. We must generate the means for information, education, and infrastructure at both the collective and individual levels – we must make Green Transportation easy, safe and smart especially for citizens.

A new local Green Transportation portal webpage must provide answers to relevant questions and influence citizens to start using green transport options. Campaigns will support people switching use to bicycles (and electric bicycles) instead of cars.

Companies with more than ten vehicles will be offered "fleet consultancy", where a consultant can contribute to a more efficient utilization of the fleet.

The Municipality is exploring the possibility of establishing a Green Transportation center to create a green service and logistics center for professional commercial and public transportation. This will create new opportunities to bundle transport logistics making better use of capacity.



The Traficpyramide
Source: Bicycle Innovation Lab

Value and impact

There are three major benefits of the Green Transportation Development Theme:

- The citizens health will improve, due more widespread use of bicycles and corresponding reduction in car traffic. This will potentially also lead to less cars in the old city center and a reduction in rush-hour traffic.
- Noise, particulate and CO_2 emissions in urban and rural areas will be reduced as more vehicles become “green”.
- Sonderborg’s green transition will be highly visible to both residents and visitors due to more green vehicles in use.

Did you know...

- More than 13% of Sonderborg´s citizens are using bicycles as a primary means of transportation.
- More than 32,000 cars are registered in Sonderborg, with an average age of 9.3 years.
- Sonderborg`s largest companies in relation to transport of goods are Danish Crown (food), Danfoss (industry), LINAK (industry), Sønderborg Forsyning (waste) and the local hospital.

Key players

- Motivation and participation of citizens are important, as citizens are private transport consumers as well as employees. It is key to improve citizens’ knowledge and experience with green transportation means.
- The Municipality of Sonderborg is a transportation front runner with its own cars and the public transportation. The municipality undertakes information campaigns on Green Transportation.
- The participation of local companies are important. Companies participate by switching company vehicles, develop low carbon logistic plans for transportation of goods etc.

A green thread in education

Sonderborg's transition to a CO_2 neutral community require that citizens and businesses understand and commit to the SixBigConcepts. Consequently, ProjectZero has created partnerships with key educational institutions to ensure that community is offered early green learning from Kindergarten to PhD and in-service training of craftsmen.

Sonderborg's House of Science is an education network which facilitates a green curriculum from Kindergarten to PhD. The curriculum's focus is on climate, innovation and sustainability. The City Council has approved the green curriculum through which the House of Science has ensured that thousands of students are actively a part of Sonderborg's great transition.

Examples:

In the winter of 2012, more than 100 citizens have joined the ZEROdriverslicense learning program. The citizens now know how to "drive" energy consumption in their homes and actively promote energy saving in local society - as Ambassadors.

Sonderborg-area's craftsmen have significantly strengthened their energy consulting. 65% have participated in energy advisor training programs. The ZEROconstruction project, also lead by EUC Syd, facilitates energy instillation skills for craftsmen in Sonderborg and other municipalities of the Southern Denmark Region. It is funded by the European Social Fund and the Southern Denmark Growth Forum.

Combing education and real world training, students from the Business Academy SydVest and the University of Southern Denmark collaborate with local craftsmen and industrial companies to solve specific cases or undertake joint projects. These partnerships have made considerable contributions.

On the finance side, the local banks and real estate companies have been trained to understand how energy efficiency can strengthen personal finances of homeowners and ensure a better selling price of real-estate in future.

New activities will include a training package for municipal schools. The package will inform children about biking and green transport. It includes child-adult interaction. In this way, young people may act as "change agents" to improve the families transport habits.

Sonderborg is in the process of becoming a UNESCO Learning City.

Foto Jacob Dall

A green mark on the global development

Countries, cities, companies and citizens are all looking for sustainable solutions that work. The solutions must be economically, environmentally and socially beneficial.

Sonderborg's ProjectZero public-private partnership has become a global role model for how society can turn local energy saving and carbon reduction ambitions into action, based on specific plans and local ownership.
In 2010, ProjectZero received the EU Sustainable Energy Award for "Sustainable Energy Communities". Today ProjectZero participates in a variety of networks and cooperation nationally and internationally. Several of these are among the world's leading climate and energy networks for cities and universities:

- The Climate Positive Development Program working with the Clinton Climate Initiative – in cooperation with C40 Cities.
- NORD-STAR - ProjectZero is the only non-university partner in the joint "Nordic Centre of Excellence" within climate research.
- Sonderborg has signed a Friendship City partnership with the Chinese City of Baoding (11 million citizens), the partnership was originally initiated by WWF in 2008.
- Sonderborg participates in the "Covenant of Mayors" cooperation which includes both European and Chinese cities. In 2012, Sonderborg was a co-signer by the EU-cooperation agreement with China.
- Sonderborg inspires and assists Chinese county Haiyan (440,000 citizens) to achieve its ambitions to become a leading Chinese role model for green urban transition in China. Sonderborg also joined the EU-China Urbanization Partnership Forum in Beijing 2013 and signed together with Haiyan as one of only 5 EU-China energy role models for city-cooperation's.
- ProjectZero initiated in 2012 a municipal network of strategic energy planning across municipal boarders in collaboration with the Region of Southern Denmark. The Network is scaling up ProjectZero's best practice solutions and in cooperation developing new solutions.
- Sonderborg has in 2015 committed to the Compact of Mayors, as the new global platform for City climate initiatives, commitment, planning and reporting.

Sonderborg attracts international attention due to two factors: Firstly, the founding partners of ProjectZero linked the climate agenda to business and job creation. Secondly, the initiation of Bright Green Business activities, including demonstrations of energy efficiency and conversion to renewable energy. Sonderborg is an awarded and recognized front-runner among the world's climate and energy networks.

Sonderborg's ProjectZero has demonstrated that it's doable to address the climate challenge at local and city/municipal level. And Sonderborg is committed to defend and preserve the position as global front-runner in order to secure local climate actions together with businesses.

The ProjectZero initiative

The ProjectZero Company was established in 2007 as a public-private partnership by SE, Danfoss Foundation, Municipality of Sonderborg, DONG Energy and Nordea Bank Foundation. Sønderborg Forsyning joined the partnership in 2014. University of Southern Denmark is also a boardmember.

The Board of Directors, in cooperation with local stakeholders, develop plans and specific initiatives to achieve the ambitious community goals, monitor results and impact and initiate corrective actions, when required.

The thinking, the lessons learned and the concepts are scalable to much bigger cities all over the world – and prove that combating the climate challenge is doable.

Bright Green Business
ProjectZero

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Headquarters.dk · 08 2015

The Land Use-based Integrated Sustainability Assessment (LUISA) Platform

Baranzelli C., Lavalle C. (JRC-IES-H8)

Scenario-based modelling is a technique employed when investigating the future evolutions of a given territory (a city, a region, a country or even the entire world). Models can be employed to simulate the direct and indirect impacts of a policy measure (e.g. an investment in an economic sector, the definition of zoning plans, the construction of a road or the installation of a technological infrastructure) or of wider trends, such as those related to climate or demography. Scenario modelling helps in combining effects of more matters simultaneously, and also in evaluating the impacts of potential or possible alternatives of evolution.

Based upon the new concept of '*Land Functions'*, the Directorate General Joint Research Centre (DG JRC) of the European Commission (EC) has developed the Land-Use-based Integrated Sustainability Assessment (LUISA) Modelling Platform to contribute to the evaluation of impacts of policies and socio-economic trends on European cities and regions.

Land functions are instrumental to better understand territorial processes and to better inform on the impacts of policy options. A land function can, for example, be physical (e.g. related to hydrology or topography), ecological (e.g. related to landscape or phenology), social (e.g. related to housing or recreation), economic (e.g. related to employment or production or to an infrastructural asset) or political (e.g. consequence of policy decisions). Commonly, one portion of land is perceived to exercise many functions. Land functions are temporally dynamic, depend on the characteristics of land parcels, and are constrained and driven by natural, socio-economic, and technological processes.

In order to cope with the European-wide coverage and multi-thematic nature of the explored territorial processes, a wide knowledge base is needed. LUISA accommodates and integrate in a consistent way geographically referenced information from diverse sources, ensuring consistency of data nomenclature, quality and resolution, in order to allow cross-country/region/city comparison. Depending on the specific application, spatial and thematic resolutions can be adjusted in order to resolve local features and provide continental patterns.

LUISA simulates land functions described by means of spatially explicit indicators. The indicators are grouped according to 6 themes, projected in time until typically year 2030 or 2050, and can be represented at various levels (national, regional or other).

A specific application of LUISA concerns the implementation of the "EU Energy, Transport and GHG emission trends until 2050 – Reference Scenario 2013"[1].

The allocation of population, activities and services (at high spatial resolution: 100x100 meter, EU28 coverage) allows to build profiles of energy consumption / use for different sectors (residential, industrial, transport, etc.). It also provides information on the availability (including costs of logistics) of resources relevant for energy production (e.g. biomass, solar suitability). Combined with the JRC-EU-TIMES model, this approach allows to compute an 'energy balance' at regional (sub-national scale). In principle, this capacity can be used to generate ad-hoc scenarios of 'optimisation' of energy production/consumption, on the basis of the characteristic of each region.

In particular for the residential sector, LUISA is equipped to downscale and project energy consumption trends, as function of buildings and households variables, climatic factors and urban characteristics (e.g. presence of green spaces).

[1] Baranzelli, C., Jacobs-Crisioni, C., Batista, F., Perpiña Castillo, C., Barbosa, A., Torres, J. A., Lavalle, C. ,2014. The Reference scenario in the LUISA platform – Updated configuration 2014 Towards a Common Baseline Scenario for EC Impact Assessment procedures.

Building Energy Consumption and Location; Big Data handling for Optimized Integration of Energy Systems in the Building Sector.

Hans Bloem, JRC – IET-REE Unit

Introduction

Careful examination of energy consumption in the building sector, which is about 38% of the final energy consumption in EU-27 (Eurostat data 2011) is needed in order to identify the specific areas for energy savings. Due to improved insulation levels of buildings this saving potential moves to more dynamic energy use sectors such as gains from appliances, high energy demand patterns (such as from heat pump) and consumer behaviour. At present, the EU residential building stock consumes about 2/3 of the energy mainly for space heating and cooling, while the remaining 1/3 (electricity) is consumed by appliances and light. The recast of the Energy Performance for Buildings Directive (EPBD) (2010/31/EU) requests for high energy performance buildings that can be fulfilled when overall building energy performance is improved, renewable energy systems are installed and storage technology is applied. It is already anticipated that the current electricity grid cannot manage this unless proper information and computation technology is put in place. The EPBD fixes the reduction of the space heating and cooling, ventilation, lighting and domestic hot water energy consumption of buildings. Since the electrical loads are characterized for being highly user dependent and stochastic by definition, this will add more complexity to the analysis and prediction of the overall energy loads of the high energy performance buildings.

Big Data.

The role out of smart electricity and gas meters will create a huge amount of data that offers an opportunity to make the realisation of the optimised energy use possible. Although metering is essentially for billing purposes it may facilitate other purpose to consumers as well as producers and distributors of electricity, gas and other forms of fuels such as district heat. The EC in its COM (2014) 356 document has reported the targets for the role out of intelligent metering in the EU by 2020 in all its Member States. Apart from an economical benefit it states that a 3% energy saving potential is achievable.

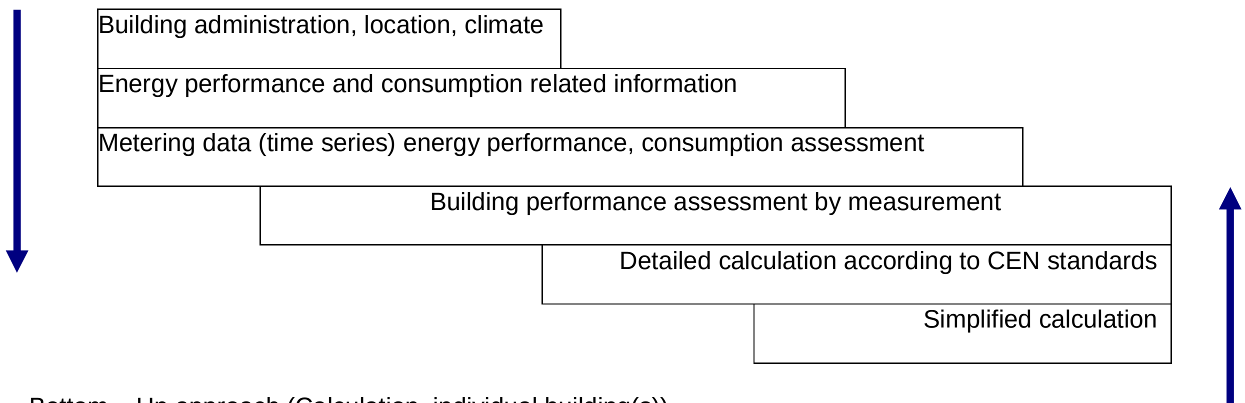
This discussion document focuses on the residential building sector, covering > 200 Million dwellings (detached, semi-detached, multi-apartment blocks, etc.) in which >500 Million people are living. The buildings as well as the inhabitants consume energy, 28% of the overall energy consumption in the EU. These numbers reflect a huge complexity dealing with different issues, ranging from billing, distribution management and GHG emissions. So the driver to reduce GHG emissions is the reduction of energy consumption in the building sector, involving > 500 Million people.

One may simplify the energy consumption to 2 sectors, e.g. the energy needed for achieving a comfortable building indoor environment in a given climate and the energy consumed by the people living and/or working in that specific environment. With the rolling out of advanced metering in the residential sector the importance of time series analysis becomes evident.

[JRC: Benchmarking smart metering deployment in the EU-27.]

An assessment of the energy performance of a building can be performed in different ways. In the schematic representation below is given a top-down approach, starting from administrative building data. A bottom-up approach starts from the calculation method as presented by the CEN standards, related to the EPB Directive and hence minimum requirements set by the individual Member States

Table 1.
Top – Down approach (empirical – databases, metering, Big Data)



Bottom – Up approach (Calculation, individual building(s))

Modelling Approach

The modern ICT sector can deliver tools that are vitally needed to collect, process and manage the data and present it in a standardized format. The approach for assessing information contained in these regular and more frequent readings is by means of application of sophisticated mathematical and statistical techniques. To assess from limited but at the same time informative observations from the metering equipment, the energy performance of the building as well as the energy consumption by the occupants can be obtained.

The model-choice as an important part of the method. A model is by definition a **simplification** of reality and a proper assessment is required in order to justify the applied model.

In relation to this assessment the **time aspect** should be considered, e.g. the impact of time related aspects of different energy related processes. This includes hourly, daily, monthly or seasonal and yearly approaches of the overall performance assessment.

- Hourly : light, ventilation, occupant behaviour
- Daily: solar gains, weather dependence, window-opening, gains, ventilation
- Monthly: seasonal: solar gains, wind, temperature, functionality, system performance issues
- Yearly: solar gains, temperature.

The consequences for the assessment are evident in particular when **the uncertainty** of the assessed performance value is taken into account. Energy labelling is in most cases performed by auditors who examine drawings, climate and other building administration, that may include age of the building, local requirements for insulation and ventilation, which may result in different label resulting values for the same object.

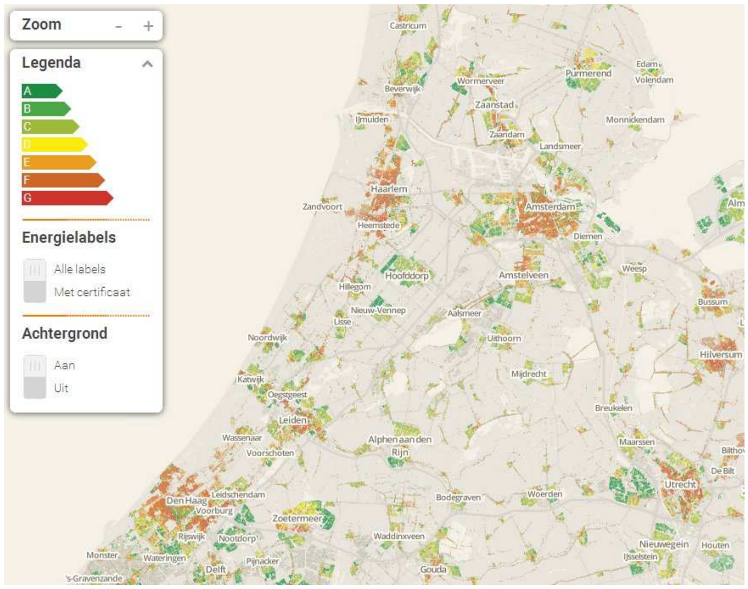


Figure 1. Relation between energy performance and energy consumption

Information on the energy performance can be made available to the building owner and energy providers or building construction companies. One way of doing so is by an energy-label as given in figure 1. The uncertainty is about 15 -20%, derived from the scaling A to G. The method behind the energy label is much simplified and not based on detailed calculation nor on measurements and should be considered as an indicator only. The indicator is mostly linked to the information from the cadastre, such as age, construction requirements, type of building and climate, e.g. location of the object.

The Energy Performance for Buildings Directive

The Energy Performance for Buildings Directive demands for the assessment of the energy performance in two ways: by calculation or by measurement. Calculation methods are provided through national standardisation for which CEN has been working hard to define a harmonised structure of sub-standards. It demands for monthly or hourly calculations using reference climate data. The well-known problem of the calculation assessment is the gap between the design energy performance value for a building and the real one.

The measurement method offers a different approach to the energy performance assessment which can be considered as more realistic although the method has the drawback of the variable climatic conditions as well as the uncertainty of the separate elements to identify areas for renovation. On-site measurements are therefore recommended for building elements (wall, roof structures etc.) and for whole buildings (including infiltration assessment) in order to derive a realistic energy performance value.

Regular measurements of energy consumption by means of metering may offer detailed information of electricity, gas and even water usage. Time series analysis of these data will give an indication of the energy required by the building due to the climate but also the energy needed for using the building, e.g. living or working.

Proposed Method

A combination of statistical and dynamic evaluation methods, are techniques that must be used to analyse time series of data related to dynamic processes and to identify occupant behaviour and typical parameters of the physical processes for evaluation. Data from smart meters are typical examples of such time series and provides details of energy usage patterns. By using dynamic evaluation techniques (system identification) dynamic effects due to accumulation of energy (heat and electricity) in the building interior construction, envelope and equipment are properly taken into account, which combined with the occupant behaviour, provides the overall vision necessary to model the residential thermal and power demand.

The aim of the herewith presented method is to derive from available metering data and climate data the amount of energy that is needed by the building to fulfil the minimum requirements for the type of building, e.g. for residential dwellings a design indoor temperature of for example 20°C. This energy need would correspond with the performance of the construction in a typical climate while the energy consumed by the occupants, their appliances and behaviour (like different indoor temperature setting) would result in the remaining part of the energy readings. See figure 2 for further explanation.

The proposed method therefore has to be able to distinguish between the building energy needs and the occupants' energy consumption.

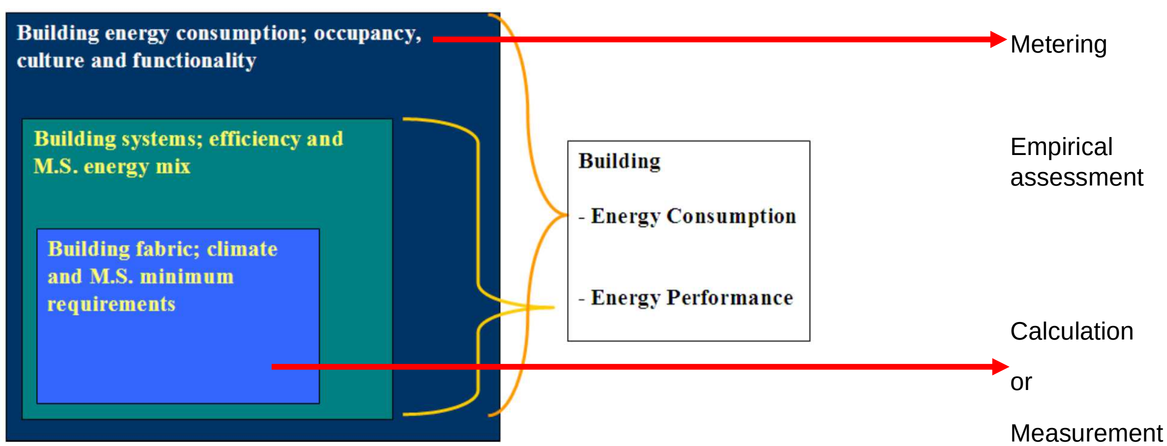


Figure 2. Relation between energy performance and energy consumption

Building energy performance and consumption assessment.

According to the EPBD the performance of the building deals with energy needed for heating, cooling, ventilation, hot water and light (for non-residential buildings), referred to as EPB use. These building energy needs are strongly related to the climate, in particular the ambient temperature, the solar radiation and the impact of wind. In general, the major part of energy consumption is required for the building energy needs.

The trick is to correlate EPB use of energy to climate and fabric parameters and to correlate non-EPB use to the user of the building. The latter includes energy consumed by appliances and the pattern of usage by the occupants. The variation depends a lot on how many appliances and people are living or working in the building comprising when energy is used. High frequency readings of electricity consumption facilitate the assessment of this information. Readings of water, heat and gas or other carriers would make the assessment even more informative.

Gathered from building administration is knowledge about the exact location and the nearest weather station for reliable climate data. Which fuel is used and what data is available, like interval, unit but also for which purpose (like gas for heating, cooking, hot water).

In order to deal with many buildings (millions) and huge amount of data (hourly, daily, etc.) it is feasible to develop a method that analysis the continuous flow of data from the object and climate. The method can be incorporated in a local device that communicates with the utilities as well as the building owner.

Discussion

Boundaries for the assessment; Member State level, building level, in-between level (City, urban area)

Top- down versus Bottom-up approach;

- where are the limits, e.g. boundaries for assessment?
- who benefits? (energy end-consumer, the energy producer/ distributor)
- what are the requirements for data input?
- what are the requirements for output results?
- uncertainty and confidentiality

References.

J. Bloem, et al. *Dynamic Methodology for the Evaluation of Occupant Behaviour and Residential Energy Consumption. EEDAL 2015, Lucerne, CH.*

H. A., Nielsen, et al. *Analysis of energy consumption in single family houses. In: DYNASTEE, 11-12 October 2010, Brussels.*

COM (2014) 356 document. *Benchmarking smart metering deployment in the EU-27 with a focus on electricity*

COM 2010/31/EU *Energy Performance for Buildings Directive (EPBD).*

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"Spatial data for modelling building stock energy needs" :

Enhancing Sustainable Energy Action Plans at local level

Albana Kona, JRC –IET-REE Unit

1. Introduction

The paper addresses the need for tools and data enabling the redaction of Sustainable Energy Action Plans at local level within the frame of Covenant of Mayors Initiative. Under the EU Covenant of Mayor Initiative, more than 6500 cities and municipalities have signed (as of September 2015), who commit to reductions in CO_2 emissions in their municipalities of at least 20% by 2020. The majority of CoM signatories (88%) are small medium towns with less than 50,000 inhabitants and they often encounter many obstacles in getting data about energy consumption at the right level of detail. The importance of small and medium-sized cities should not be underestimated. The generic features of small and medium-sized cities – particularly their human scale, liveability, the conviviality of their neighbourhoods, and their geographical embeddedness and historical character – in many ways constitute an ideal of sustainable urbanism[1]. Europe is characterised by a more polycentric and less concentrated urban structure compared to, for instance, the USA or China[2]. 56 % of the European urban population – around 38 % of the total European population – live in small and medium-sized cities and towns of between 5 000 and 100,000 inhabitants. Furthermore, in Europe, CO2 emission per person is much lower in urban areas compared to non-urban areas[3]. The density of urban areas allows for more energy-efficient forms of housing, transport and service provision. Consequently, measures to address climate change may be more efficient and cost effective in big and compact cities than in less densely built space.

Local authorities prepare sustainable energy plans often in the frame of national strategies and aiming for ambitious energy efficiency and decarbonisation goals. These plans often consider the heating system in an integrated way, looking at the evolution of the whole energy supply and demand in a municipality to define the least cost approaches.

Therefore, reliable data, at national and at local level, are necessary in all the phases of the policy life cycle, from inventories, planning to implementation and monitoring. Valuable support to satisfying these data needs can be provided by the INSPIRE Directive (2007/2/EC) : INSPIRE is the reference directive for spatial data, establishing an infrastructure for spatial information in Europe to support Community environmental policies, and policies or activities which may have an impact on the environment, such as energy policies. The INSPIRE Directive is well-timed as it is due to be operational by 2020, when MS have to report about data which are of interest for CoM.

1 Farr, D., Sustainable Urbanism : Urban Design with Nature, John Wiley & Sons, New Jersey, 2008
2 source DG Regio: Only 7 % of the EU population live in cities of over 5 million inhabitants compared to 25 % in the USA
3 A rural resident would consume an average of 4.9 tonnes of oil equivalent/year in Europe while a city resident would consume 3.5 tonnes of oil equivalent. Source : IEA, 2008 and World Energy Outlook, 2008, International Energy Agency, Geneva

Based on this background, the "Location data for energy efficiency policies" feasibility study aims to verify the potential for an effective application of spatial data to support the monitoring requirements of the different EU energy efficiency policies and initiatives, which include data from different sources and at different scales (building, district and national).

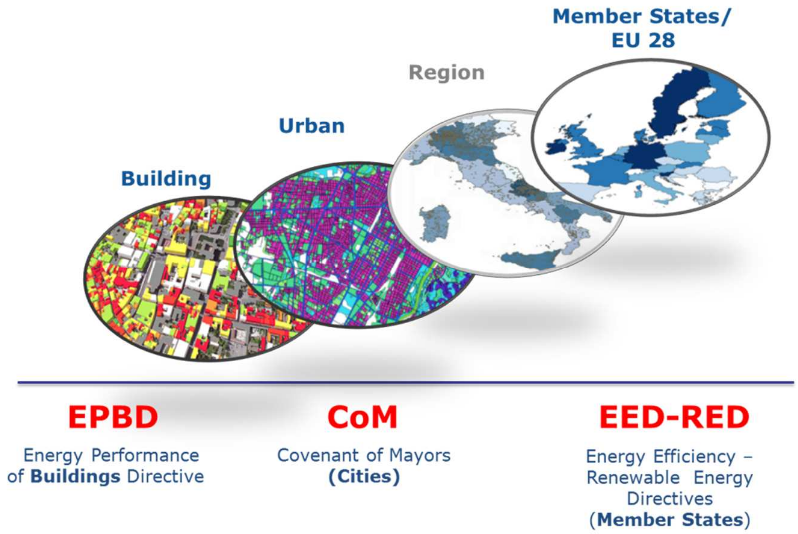


Figure 1. The different scales in the application of energy efficiency policies

2. Data requirement for CoM

In the Covenant of Mayors special focus is placed on the data collection required for the Sustainable Energy Action Plans (SEAPs) prepared by CoM Signatories, "where local and detailed data about energy needs and consumptions are needed at different geographical scales".

In the SEAPs the data collection process and the data sources should be well documented and publicly available, so that the process is made transparent and stakeholders can be confident with the inventory of emissions.

Data should be relevant to the particular situation of the local authority, i.e. based on energy consumption / production data, mobility data etc. within the territory of the local authority, and estimates based on national or regional averages are not considered appropriate as they would not capture the efforts made by the local authority to reach its CO2 targets[4].

In all of this, the collection of reliable data with an acceptable level of accuracy is one of the most difficult tasks in designing, implementing and monitoring a SEAP.

The SEAP template allows signatories to report data concerning their action plan, namely the adopted target, the Baseline Emission Inventory and the actions planned to achieve the target. The Monitoring template focuses on tracking progress in SEAP implementation. The templates are composed of three main parts as described in the following figure.

[4] SEAP guidelines (EU, 2010b, p.9)

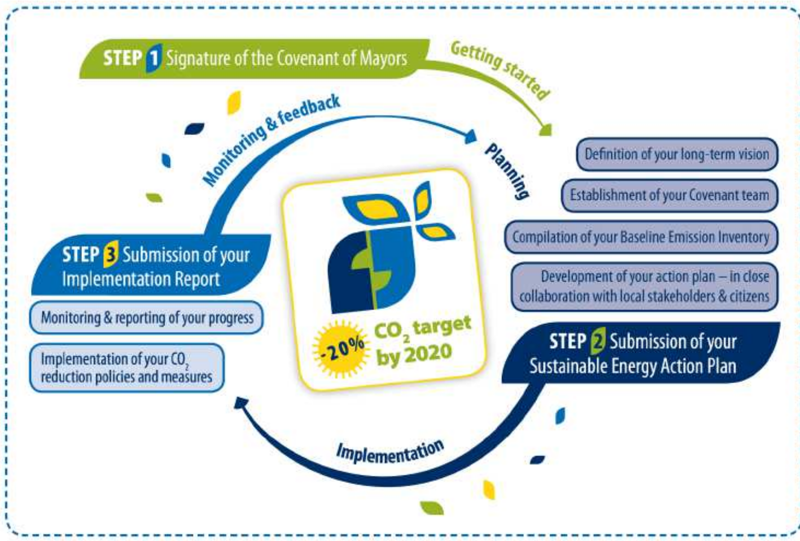


Figure 2. Sustainable Energy Action Plan process in the framework of Covenant of Mayors

3. Modelling approach

To achieve the 2020 climate objectives, modelling forecasts illustrate the need for the EU to move away from fossil fuels to low carbon sources and deeply transform its energy system.

There are tools that could be useful at local/regional levels to explore the different pathways and identify of the options for action which are necessary to drive the changes needed to achieve the sustainability goals. In buildings there is scope for speeding up the renovation rate. While heat demand is reduced, the focus should also be on the supply of heating or cooling to ensure a gradual transition to renewable energy fuels and the increase fuel, carbon and conversion efficiency for the remaining part of fossil fuels (eg. SEAP of Sønderborg).

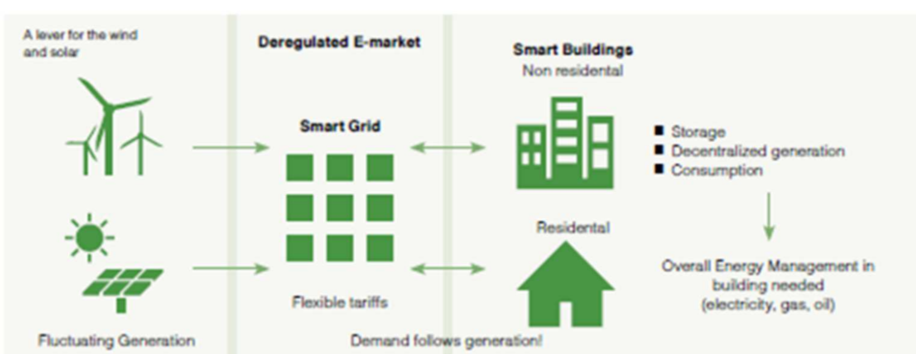


Figure 3. SEAP of Sønderborg : SmartEnergy stabilizes the balance between supply and demand of energy

In the following some examples of methodological approaches to allow for analysis of scenarios with a focus on the heating sector are reported for enabling the SEAP redaction of CoM signatories.

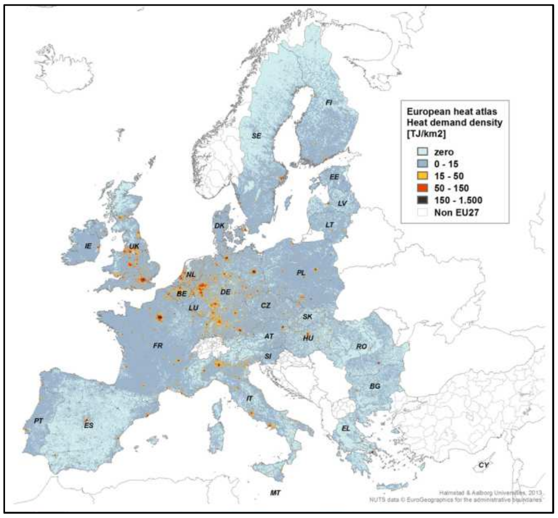


Figure 4. European Heat Atlas Demand density

An hourly heat modelling approach combined with the mapping of heat densities and renewable and waste heat resources at European level has been developed by a consortium led by Alborg University.

The European Heat Atlas has been used as a tool for modelling energy demand in some cities CoM signatories in the above countries (eg. London). The results have quantified the share and the energy, environment and investment, system cost impacts of installing district heating and individual heating and cooling appliances in the EU energy system. Since then, several other studies have been developed, focusing on national or local energy systems. The IEE Stratego project[5] applied holistic energy system analysis to perform comprehensive assessments for heating and cooling for five Member States: the Czech Republic, Croatia, Italy, Romania, and the United Kingdom.. To begin the mapping of heat demands is done in a top-down manner, where national level energy statistics allows for the calculation of Member State average per-capita heat demands, which are subsequently associated to total population counts within each NUTS3 region in each respective country. Afterwards, the general climate of each Member State is represented by use of the European Heating Index (EHI), a concept presented by Werner (2005)[6], to map sub-national deviations from national and European heat demand averages. Using the EHI adjusted heat demands per NUTS3 region, the European population grid (by GISCO 2012) was converted to highly detailed heat atlas for Europe[7].

Adequate planning is required as only in this manner the efficiencies and the use of renewables can be maximised. Examples of this could include, for instance, those situations in which a city planning authority grants approval for new development on the condition of connecting to an existing heating network. Also, some cities have developed guidelines and (GIS) systems to decide the depth and the situation of the wells that are required to supply ground source heat pumps.

Heat planning by municipalities in Denmark has recently been complemented by national level assessment for heating and cooling and the relevant energy sectors. For example:

[5] http://stratego-project.eu/

[6] Werner, S., 2005. Ecoheatcool: The European heat market (WP1). Euroheat & Power, Brussels. Available from: 〈http://euroheat.org/ecoheatcool〉

[7] Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system. Energy Policy 65(2014) 475–489. D. Connolly et.al.

Energi2020 is Ringkøbing-Skjern Municipality's[8] vision to become self-sufficient in renewable energy by year 2020. This means that we produce as much renewable energy as the citizens and businesses in the municipality consumes. For that purpose, GIS-based energy atlas has been developed for Ringkøbing-Skjern municipality. The data about energy supply and demand, transmission and distribution infrastructure, energy resources, societal and other energy data have been geographically referenced and combined with the tools built in ArcGIS.

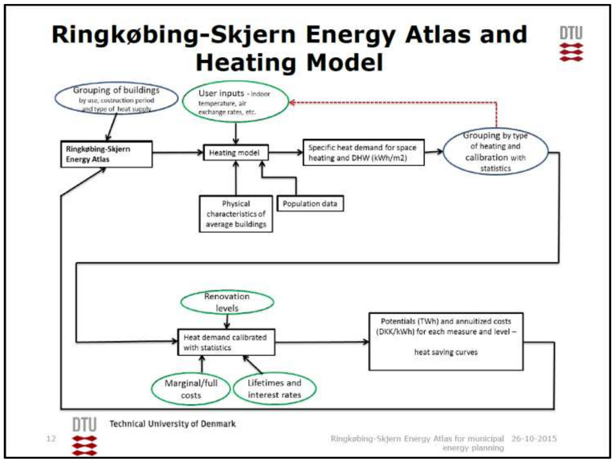


Figure 6: Ringkobing–Skjern Energy Atlas and Heating Model

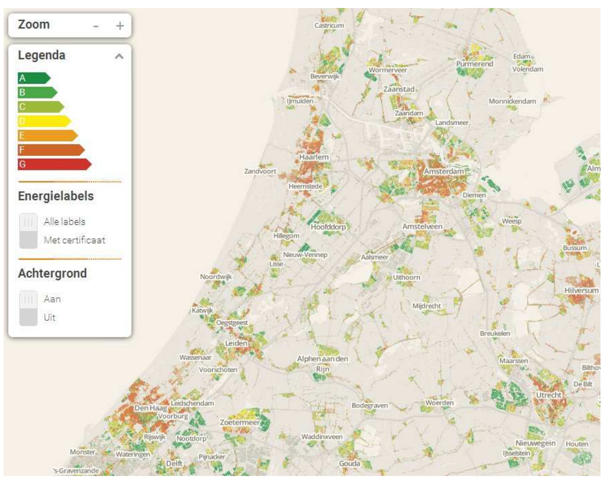


Figure 5: Energy Labelling Atlas in the Netherlands

The Energy labelling Atlas in the Netherlands[9] provides an identification of the energy performance of individual buildings. The Atlas Energy uses three types of energy labels, which differ in completeness of housing data: 1 star: Energy based on a number of standard housing characteristics from public sources such as the year of construction, floor area and number of floors; 2 stars : Energy adjusted using the button 'Check my label'; 3 stars: Energy label by certified consultant. In the modelling of default values, assumption has been made, such as the one on the glazing area (glazing this covers 25% of the façade.). Based on this atlas city of Amsterdam, is enhancing the quality of the SEAP by upgrading it into a Energy Atlas Plus including the mapping of renewables.

4. Discussion

The mapping of CoM signatories, along with energy and emissions indicators, will be developed in the pilot study. This will allow local authorities to rely on high quality and local data to better inform the planning of energy efficiency measures.

[8] Ringkøbing-Skjern energy atlas for municipal energy planning: SDEWES 2015. Stefan Petrović, Kenneth Karlsson

[9] http://www.energielabelatlas.nl/#

The aims of the EULF Pilot Project on "Location data for energy efficiency policies" include the following:

a) To support local authorities (e.g. Covenant of Mayors signatories) to enhance the energy efficiency policy-making process (from planning to implementation and monitoring), improving the quality of data they use (particularly time series local data).

b) To develop a methodology and to provide local authorities with tools to build and update a robust inventory of reliable local energy performance of buildings data (not only based on statistical indicators), to generate energy density maps, a dashboard of indicators and changes over time of energy performance.

c) To provide local authorities with tools to share data of better quality related to energy consumption, which can be used by citizens and businesses, including energy saving companies.

d) To put in place harmonised data flows to support energy related initiatives at local level (e.g. the CoM) and to align them with the national energy efficiency planning obligations (set by the Energy Efficiency Directive or the Renewable Energy Directive).

The Use of Spatial Data for Energy and Exergy Mapping of University Campuses with Implications for a Net-Zero District in Sweden

Dr. Şiir KILKIŞ

1. Introduction: Energy Efficiency Directives and Initiatives

The use of location specific data presents multiple benefits for modeling the energy needs of the building stock. This contribution for the "**JRC EULF Workshop on Spatial Data for Modelling Building Stock Energy Needs**" focuses on future-oriented perspectives for combining location specific energy, exergy (the quality of energy), and CO_2 emissions data. The pilot case studies are based on two university campuses in cities that are signatories to the Covenant of Mayors (CoM) [1]. These cities are namely Delft in the Netherlands and Stockholm in Sweden, the latter of which has advanced to the monitoring stage of the Sustainable Energy Action Plan (SEAP) [2]. The diffusion of using the method of collecting location specific data from university campuses to the urban level has the potential to represent "**Case 5**" of the envisioned cases for the European Union Location Framework (EULF) Pilot Project [3]. Both cities can have the opportunity to couple demand and supply side data, including energy production, to monitor the progress that is being made towards sustainable energy landscapes. The cases demonstrate the use of spatial data for the mapping of different scenarios for building clusters in university campuses, which represent the way in which geo-location data can be used to support action in the policy domain of energy.

The contribution concludes with further implications of the use of spatial data for net-zero districts in Sweden that are to use fourth generation district heating networks [4]. The methods that are involved can support common methods to use energy based spatial data for the betterment of urban areas in the context of the Infrastructure for Spatial Information in the European Community (INSPIRE) Directive [5], including various energy density maps.

2. Proposed Mapping of Location and Energy, Exergy and CO_2 Emissions Data

Figure 1 represents the main data point inputs that are needed to realize mappings of energy, exergy and CO_2 emissions data at the building level with a spatial dimension. In Figure 1, $E_{x.y}$ represents an energy data input for a particular building with spatial coordinates x and y while similarly, $\varepsilon_{x.y}$ and $C_{x.y}$ represent the exergy and CO_2 emission data inputs for the same set of buildings. The multi-dimensional mapping of building level data with a spatial dimension for energy, exergy and CO_2 emissions can enable a thorough process of planning at multiple stages, namely stages of energy planning, exergy planning, and CO_2 emissions planning.

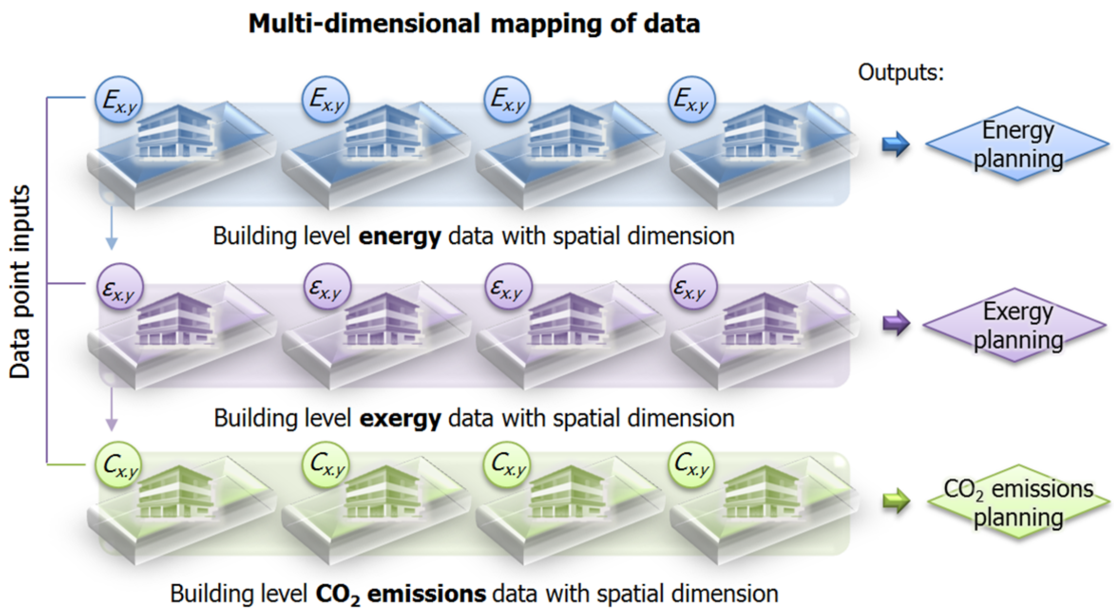


Figure 1. Multi-dimensional mapping of building level energy, exergy and CO_2 emissions data

Such an integrated approach provides benefits to consider the energy performance of buildings. At the same time, the level of match between the demand and supply of energy resources to satisfy building services based on the quality of energy (exergy) enables an additional stage of planning to increase the exergy performance of buildings. These may provide further opportunities to consider optimized community energy supply structures beyond the building level, such as district heating and cooling (DHC) networks based on renewable energy driven combined heat and power (CHP) options. According to Heat Roadmap Europe [6], DH/C networks are expected to more than double by the year 2030.

In addition, at least one of these inputs may be used to determine the CO_2 emission impacts of buildings. For example, the Rational Exergy Management Model [7] provides the avoidable CO_2 emissions impact in the energy system based on any mismatch between the supply and demand of exergy. Two case studies that have integrated an exergy aspect in the multi-dimensional mapping of building level data are provided in this contribution. As indicated in Figure 2, these two case studies focus on the scales of a university campus and building clusters within university campuses and the urban vicinity. The results of these pilot cases are further evaluated based on the implications for advancing spatial planning in a net-zero exergy district in Sweden, i.e. the Östra Sala backe project as analyzed in Refs. [8-9].

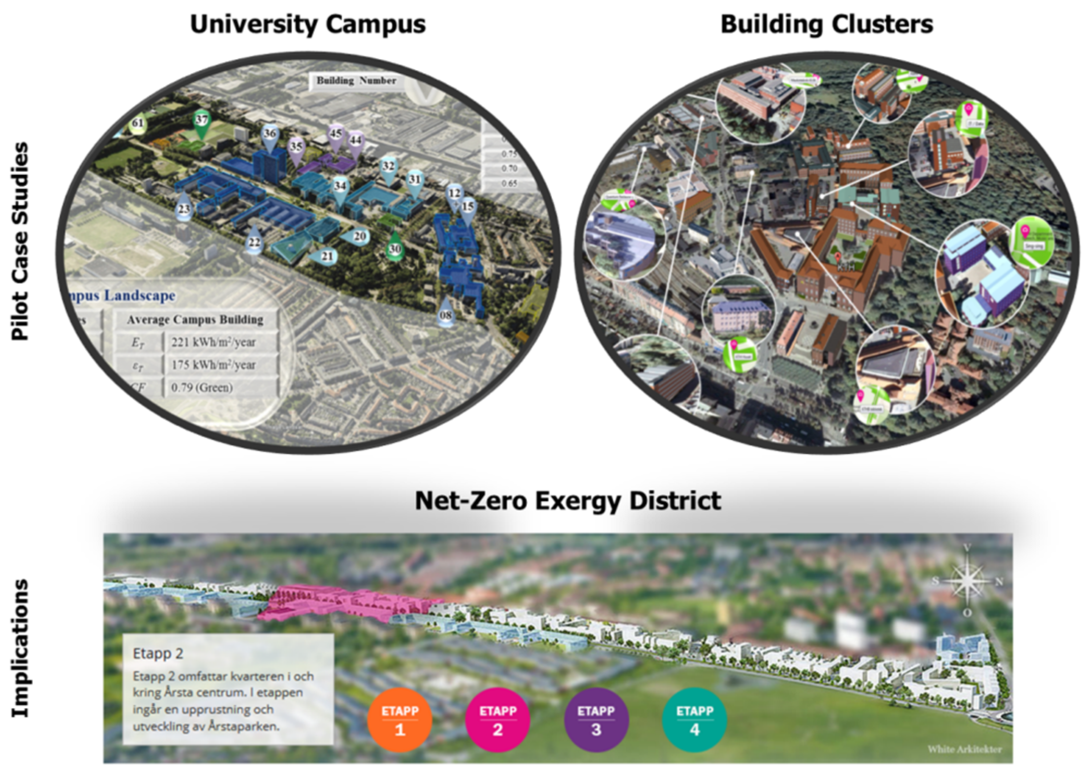


Figure 2. Scope of the Contribution and Implications for Net-Zero Exergy District

2.1. Current State-of-the-Art Example 1: Energy Label Atlas (Building Level)

The Energy Label Atlas of the Netherlands [10] provides an identification of the energy performance of individual buildings. Such an application is one of the best practices in combining energy and location data as given in the JRC Technical Report on "Location data for buildings related energy efficiency policies" [11]. Figure 3 provides a screenshot of this atlas for the city of Delft in the south of the country. With some exceptions, the buildings that do not have a label in this atlas (see grey areas) represent the campus buildings of the Delft University of Technology (TU Delft). In the first case study of this contribution, all of the campus buildings were subjugated to the proposed energy, exergy, and CO_2 emissions mapping technique. The results were used for planning in multiple aspects for scenarios.

Figure 3. Screenshot of the Energie Label Atlas [10] for an area representing TU Delft (dotted line)

2.2. Current State-of-the-Art Example 2: BPIE Data Hub (Country Level)

Another relevant example for energy and location data as provided in the JRC Technical Report [11] is the BPIE Data Hub [12]. In contrast to the building level focus of the Energie Label Atlas [10], the focus of this database is on providing aggregated data for the building stock of European countries. Figure 4 provides a screenshot of an exemplary dataset for Sweden that indicates the average heating related energy consumption of multi and single family houses by age groups. Accordingly, there are significant energy savings in younger buildings. Beyond this location based energy data for the building stock of Sweden, the second case study of this contribution will provide an original analysis for the campus buildings of the KTH Royal Institute of Technology and the university related district of Albano. The dataset for this case study involved Akademiska Hus, which owns university buildings in Sweden and is in the process of monitoring energy data as provided in Figure 5.

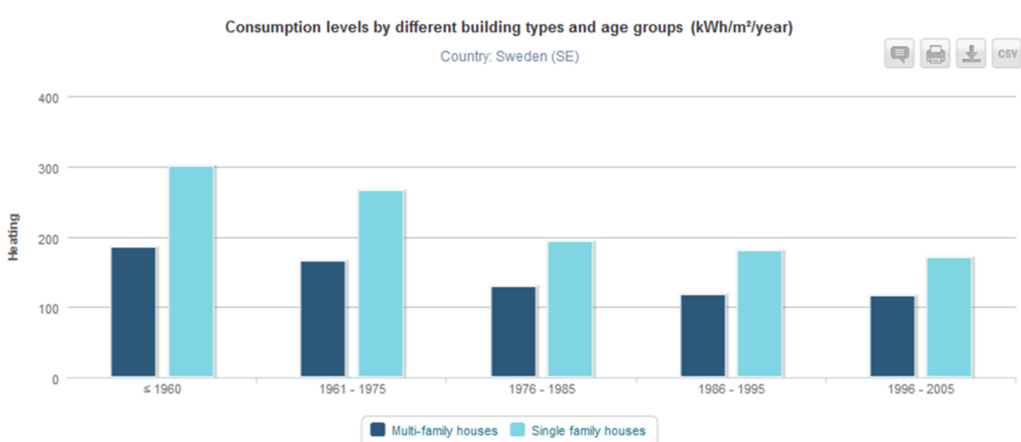


Figure 4. Screenshot of the BPIE Data Hub [12] for Sweden as the Country of Case Study 2

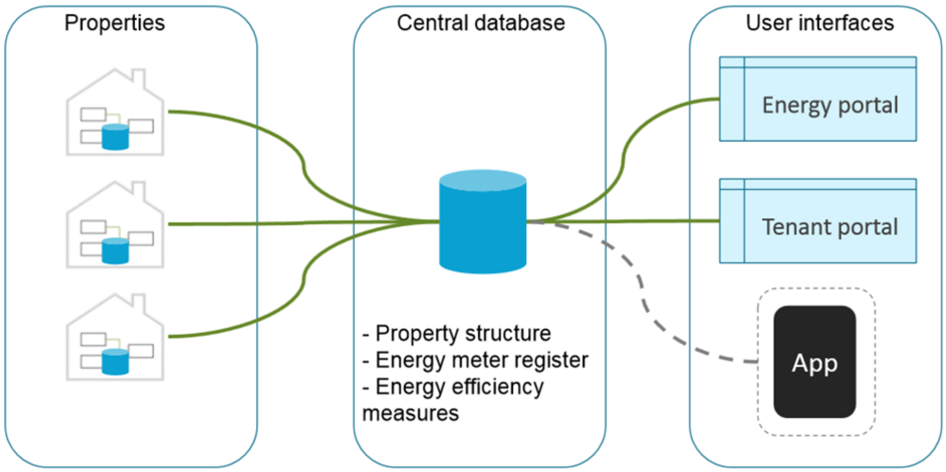


Figure 5. Screenshot of the Akademiska Hus Energy Portal for University Campus Buildings [13]

3. Pilot Case Studies with Potential for Scale-Up as EULF Partner Cities

Beyond examples from the state-of-the-art as given above for buildings and the building stock, as well as other examples for the energy density maps of districts, including those in Italy [11], the pilot case studies of this contribution represent the use of building level spatial data for the planning of more sustainable energy landscapes. In this way, these case studies indicate the use of location specific data for scenario analysis to assist decision-makers in selecting desired policy outcomes. The two case studies are overviewed below in detail. Table 1 compares some of the domains of consideration within the foreseen aims of the EULF pilot project and expectations from potential partner cities with the pilot case studies.

Table 1. Comparison of EULF Domains of Consideration and Pilot Case Studies

EULF Domains	Pilot Case Studies
Desired output to be produced	Energy, exergy and CO_2 emissions mapping
Functionalities of the demonstrator	Survey of building and energy system data
Assessment methodologies to be applied	Data analysis and scenarios for sustainable energy
Data flows to be managed by the demonstrator	Building/building cluster/building stock energy data
Data sources to be used into the data flows	Energy monitoring portals/energy labels as available
Data harmonization steps to be carried out	Application of Carnot and CO_2 emission factors

The proposed method has the potential to be in line with the Boolean attributes in the INSPIRE data model for buildings. For example, the attribute “energyPerformance” can be used to store information related to the energy label [11]. The attributes of “heatingSource” and “heatingSystem” can be used to store information related to the source of energy used for heating (i.e. electricity, natural gas, etc.) and the system of heating (i.e. stove, central heating, heat pump, etc.) [11]. Such attributes can be used to find exergy and CO_2 emissions data when the different options are combined with the relevant Carnot factors and CO_2 intensities. Standard values for these options can be defined before the operational phrase of the INSPIRE Directive and related reporting by the EU member states by the year 2020.

3.1. Case Study: *Energy and Exergy Mapping of University Campus Buildings at TU Delft*

As the site of the first case study, data was collected for the TU Delft campus. The university is committed to reducing the consumption of fossil fuels per m^2 of gross floor area by 30% compared to 2005 levels until the year 2020 [14]. This target is part of the long-term agreement (MJA3) between the Dutch government and Dutch universities to improve energy efficiency by 2% per year until 2020. The university further aims to have at least a 50% share of renewable energy in the future, including the usage of geothermal energy [14]. Based on the system boundary of the campus, data was collected at two complementary levels.

Building level data. At the building level, data was collected based on the TU Delft Energy Monitor that provides the primary energy consumption, electricity usage, natural gas usage, heat usage, and CO_2 emissions of each faculty and building [15]. The function and operational activity of the buildings are among the factors that affect energy use profiles. The portal is part of a greater effort to make the energy usage of the campus public and transparent while inviting the campus to make suggestions for improvement [15]. Annual reports for the most recent 5 years for 28 buildings on the university campus were extracted from the portal. The portal also provides the total number of 40W light bulbs at the building level, which is already represented within the electricity use profile, as well as the total amount of water usage at the campus level. The building level energy data represents the end-use or the sink for energy usage on campus.

Energy system data. On the source side of the energy system, the means of energy conversion and energy production are other essential components for data collection. In addition to the initial heat plant that continues to produce most of the heat for the campus, the campus is equipped with two new CHP units that produce both electrical and thermal energy. These CHP units, which were installed in 2011, each have an electrical capacity of 3.7 MW_e and thermal capacity of 3.7 MW_t [16]. The two CHP units and the boilers feed the heat distribution network that has 4 transmission pipelines [17]. The supply temperature of the hot water in the heat distribution network that reaches the buildings varies between 80°C and 130°C based on the outdoor air temperature [17]. An annual average was taken to be about 105°C (378.15 K).

Communication with university officials confirmed that some buildings satisfy their entire thermal load based on the use of heat from the heat distribution network while other buildings directly combust natural gas, mostly for heat-only boilers, hot water supply, and/or laboratory use [18]. Three buildings are also equipped with heat pumps based on Aquifer Thermal Energy Storage (ATES). Based on the average of energy data for the most recent 5 years, i.e. between 2010 and 2014, the average shares of the energy use profile of buildings, including laboratory facilities, were found to be about 47% electricity, 34% heat from the campus network and/or ATES (relatively minor share), and 19% natural gas for individual building level use and boilers.

Figure 6 depicts a schematic of the energy system of the campus that provides the larger context of the analysis for the building level data. The components of the schematic are the purchased electricity and purchased natural gas that are used directly or converted into delivered electricity, delivered heat, and delivered natural gas (see components of Figure 6). Conversion processes depend on CHP units at the campus level and heat boilers, either at the campus level that feed the heat network or the individual building level. The energy values in the system schematic are for illustrative purposes only for a representative year in the TU Delft Energy Monitor [16].

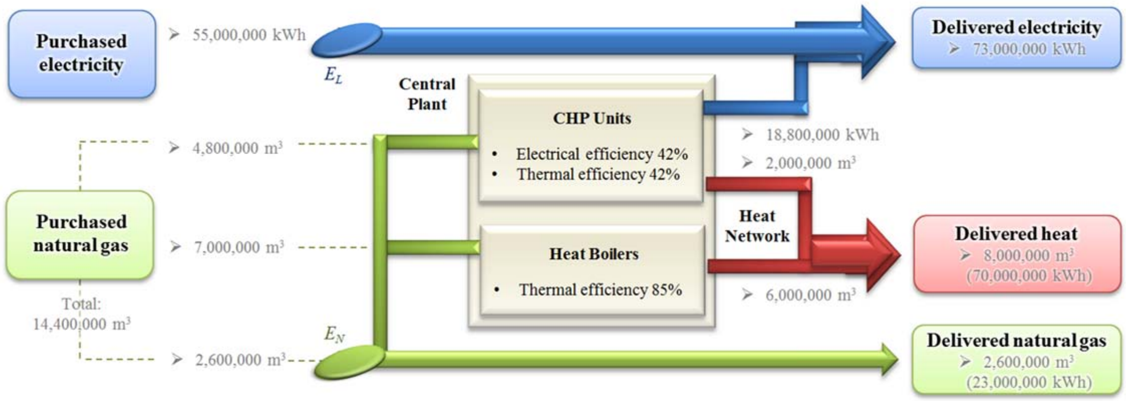


Figure 6. Schematic of the Energy System of the Campus based on Ref. [16] (Present Case)

In the future, a substantial part of campus buildings is planned to be supplied by a lower temperature heat distribution network based on geothermal energy. In this project, namely the Delft Geothermal Project (DAP), the supply temperature is aimed to be 75°C (348.15 K) [14]. On the demand side, campus buildings are expected to be completely renovated in the next 15-20 years with a focus on the use of sustainable energy [15]. Such a conjecture amplifies the importance of energy landscape mapping as conducted in this research work for the campus.

Data processing

The collected data at both the building and campus energy system level were processed to bring them in conformity with the aims of the research work. Figure 7 provides the compilation of the building level data based on average energy values for the amount of electricity, heat, and natural gas that was delivered to each building between the years 2010 and 2014. In this respect, Equation 1 was used to find the average values during the most recent 5 years. Here, E_L is the delivered electricity, E_H is the delivered heat, and E_N is the delivered natural gas for a particular year, y. E_T bar represents the average amount of energy delivered in total to each building. The components of total delivered energy as the stacked bars represent each term in Equation 1.

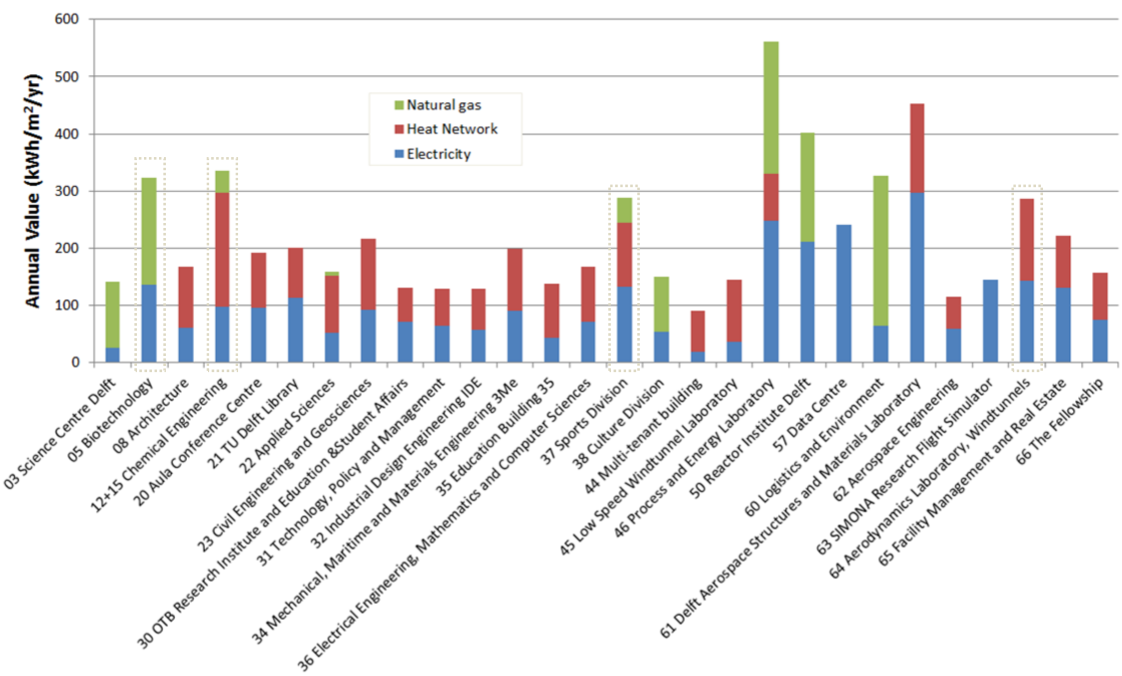


Figure 7. Data Processing of Energy Data for TU Delft Campus Buildings

$$\overline{E_T} = \sum_{y=1}^{5} E_L / 5 + \sum_{y=1}^{5} E_H / 5 + \sum_{y=1}^{5} E_N / 5 \quad (1)$$

At the same time, both Equation 1 and Figure 7 represent a summation of energy amounts with different useful work potentials or qualities. For example, the Biotechnology and Chemical Engineering buildings appear to use similar amounts of total energy at about 330 kWh per m^2 per year. A similar situation applies to the Sports Division and the Aerodynamics Laboratory. These buildings are not using energy at the same quality levels, e.g. electricity versus heat.

Electricity can be used for a more diverse spectrum of energy services from lighting to powering electronic laboratory equipment. Natural gas also can be converted into electricity to provide for the same energy services. On the other hand, thermal energy, either based on the by-product of electricity production or other sources, has a limited range of energy services in which it may be used. The degree of diversity in satisfying a broader range of energy services is due to the useful work potential of energy resources, i.e. exergy. For this reason, further processing of the energy data was needed to differentiate these aspects and bring an exergy view into the research work.

Exergy calculations. Exergy is the part of an energy flow that can be transformed into any other form of useful energy and depicts the potential of a given energy quantity to perform work [19]. In this way, it is a measure of the useful work potential of energy and can indicate the quality of energy carriers on the supply side and the desired quality of energy loads on the demand side.

In Equation 2a, the average values of each term in Equation 1 as given by E_L, E_H, and E_N are multiplied by the respective Carnot factors (*CF*) to obtain the total exergy, ε_T. The *CF* for electricity is accepted to be 1 since all of electrical energy can theoretically be converted into mechanical energy [19]. For thermal energy, the Carnot factor is based on the temperature differential that is being made with a reference environment as represented in Equation 2b. This factor results in the asymmetry between energy and exergy values [20]. T_{ref} is the reference environment temperature and T_f is the temperature of the resource being used, e.g. combustion temperature for natural gas or the supply temperature of waste heat after electricity production.

Since all of E_H is not based on the supply of thermal energy from the CHP, the appropriate share that must be multiplied by the respective *CF* is defined based on a share, *S* (see Equation 2a). As a result, a certain share of E_H bar is multiplied by CF_H and the remaining share is multiplied by CF_N. Based on Figure 6, the share of heat in the campus heat network based on the CHP units was calculated to be 25%. The remaining 75% of the heat is produced based on heat-only boilers. Table 2 provides the values that are used or obtained in Equation 2b for these instances.

$$\varepsilon_T = \left(CF_{EL} \times \overline{E_L}\right) + \left(S \times \left(CF_H \times \overline{E_H}\right) + (1-S) \times \left(CF_N \times \overline{E_H}\right)\right) + \left(CF_N \times \overline{E_N}\right) \quad (2a)$$

$$\text{where} \quad CF = \left(1 - \frac{T_{ref}}{T_f}\right) \quad . \quad (2b)$$

In Table 2, the reference environment is defined based on the ground temperature that is the ultimate sink for the seasonal swings in outdoor air temperatures [21]. The ground temperature is found to be in thermodynamic equilibrium at a depth of 9.1 m for a given location [22]. For the Amsterdam – Delft area, the value of the ground temperature is given to be about 285.5 K [23]. The units of all temperature values in Equation 2b must be expressed in units of kelvin (K).

Table 2. Temperature Value Inputs into Exergy Calculations for Campus Energy Resources

Kinds of Thermal Energy E_H	T_{ref} (K)	T_f (K)	*CF*
• Heat based on heat-only boilers	285.5	2000	0.86
• Heat based on waste heat in CHP	285.5	378.15	0.25
• Heat based on ATES systems	285.5	318.15	0.10
• Heat based on geothermal wells	285.5	348.15	0.18

In addition, three of the campus buildings, namely the 3Me Faculty (building 34), the TU Delft Library, and the EEMCS[1] Faculty (building 36) use heat pumps based on ATES. These systems provide an advantage to upgrade low quality energy at about 13 – 16 °C (286.15 – 289.15 K) to heat and/or cool buildings [24]. As a result, lower temperature heating is supplied on-site to the building at about 45°C that reduces the intake of heat from the heat distribution network. At the TU Delft Library, ATES is sufficient to cover 20% of the required heat in the winter [17]. In the future, a geothermal well at a depth of 2.3 km is also intended to supply heat at 75 °C (348.15 K) [14]. While not yet realized, this value is also included in Table 2 for comparison.

The application of Equation 2 to the energy values in Figure 7 will provide a more accurate sum that takes into account the differing quality levels of the various components of the total delivered energy. Figure 8 provides the application of Equation 2 to the energy data for the 28 campus buildings. These values represent the total exergy that is used by a building, ε_T. Buildings that had similar total energy values at different exergy levels are now differentiated.

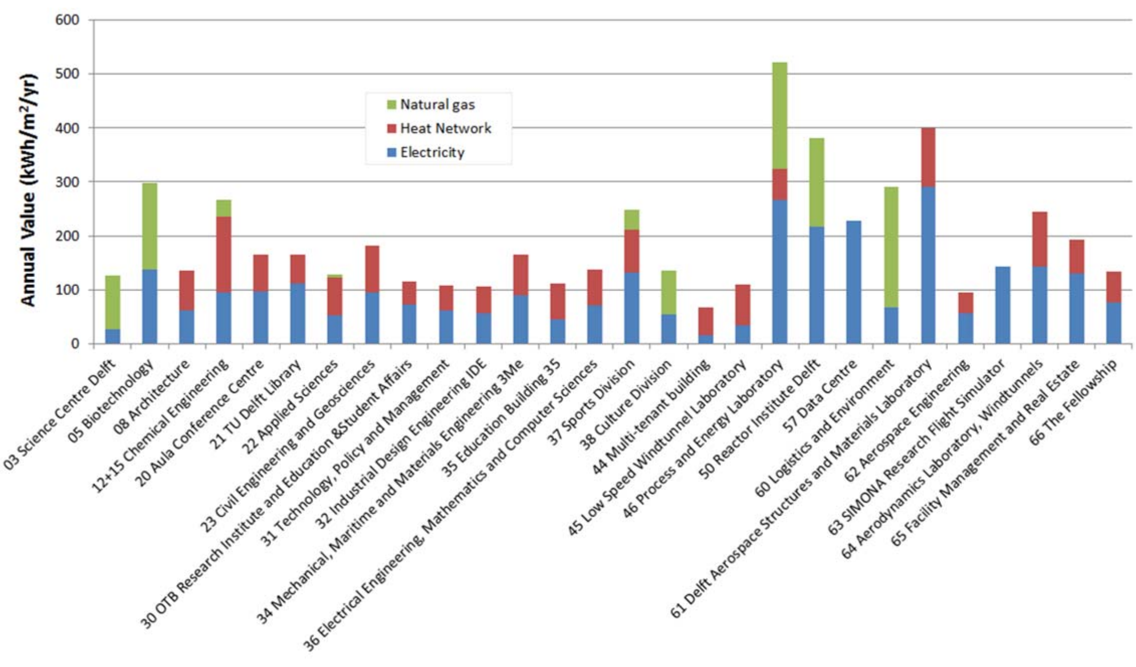


Figure 8. Data Processing of Exergy Data for TU Delft Campus Buildings

[1] The Electrical Engineering, Mathematics and Computer Sciences Faculty

$\underline{CO_2 \text{ emission calculations.}}$ The TU Delft Energy Monitor provides the CO_2 emissions of each building on the campus. These values are based on the product of the total delivered energy and the CO_2 intensity of the energy mix. This intensity also takes into account the inefficiencies between the primary energy spending at the energy system level and the energy that is delivered to the buildings. Further data processing of 5 year data indicated that the average overall energy efficiency of the energy reaching the buildings, including the inefficiencies in the plants, electric grid, boilers, and heat network, is 0.60. Based on the relations between the boundary conditions, the average CO_2 intensity was found to be 0.22 kg CO_2 per kWh of primary energy and 0.37 kg CO_2 per kWh of delivered energy that involves the value of 0.60. In comparison, this is a lower intensity than the standard CO_2 emissions factor for consumed electricity in the Netherlands at 0.44 kg CO_2 per kWh_e [25]. Equation 3 unifies the boundary conditions and represents the CO_2 emissions that are directly or indirectly emitted by the energy use of the buildings, ΣCO_2. Here, c is the CO_2 intensity of the energy resource, i.e. 0.202 kg CO_2 per kWh for natural gas [26], η is the average overall energy efficiency, E_T is the delivered energy, and E_{PE} is the primary energy.

$$\sum CO_2 = (c/\eta) \times E_T = c \times E_{PE} \tag{3}$$

At the same time, the level of match between the supply and demand of exergy can indicate the ability or inability of a particular energy allocation to reduce primary energy spending at the energy system level [7]. For example, when a high exergy resource, such as natural gas, is used to satisfy a low exergy demand, such as space heating, there is a low level of exergy match. This situation results in an additional spending of primary energy resources at the energy system level to make-up for the exergy that is destroyed at the building level without being used, such as the re-supply of natural gas to produce electricity. When the scope of analysis is broadened to the energy system level, it is clear that there can always be better uses for exergy that is supplied in excess of the exergy demand. The additional CO_2 emissions impact that arises in the energy system based on the level of mismatch in the supply and demand of exergy is provided by the Rational Exergy Management Model (REMM) [7]. As developed in Ref. [7], Equation 4 provides the compound CO_2 emissions as the sum of direct and indirect CO_2 emissions and the avoidable CO_2 emissions impact in the energy system due to the level of exergy mismatches.

$$\sum CO_{2i} = \left(\frac{c_i}{\eta} + \frac{c_j}{\eta} \left(1 - \overline{\Psi}_{Ri}\right) \right) \times E_T \tag{4}$$

In Equation 4, the first term that is multiplied by E_T involves the ratio of c and η as given in the previous equation to unify the boundary conditions. In contrast, the avoidable CO_2 emissions impact (second term) involves the ratio of the average CO_2 content of the energy resources that are used at the energy system level, c_j and the parameter, ψ_{Ri}. The parameter ψ_{Ri} bar indicates the average level of match between the supply and demand of exergy as the rational exergy management efficiency. Table 3 provides typical values for various technological options based on Ref. [7]. These options are limited to those that pertain to the energy system of the campus.

Table 3. Typical Values for the Parameter ψ_{Ri} based on Ref. [7] and/or Calculated

Technological Options	ψ_{Ri}
• Heat based on heat-only boilers using natural gas	0.04
• Cooling based on electricity from the electric grid	0.04
• Heating based on pumping of heat from geothermal wells	0.24
• Electricity based on electricity only power plants	0.35

• **Heating and/or cooling with heat pumps based on ATES**	0.42
• **CHP (including electricity and thermal energy components)**	0.80

As indicated in Table 3, the value of the parameter ψ_{Ri} for the provision of heat from heat-only boilers using natural gas is 0.04. In contrast, the value of the parameter ψ_{Ri} for CHP is about 0.80. The values of the parameter ψ_{Ri} range between 0 (poor level of exergy match) to 1 (best level of exergy match). CHP represents a better level of exergy match than heat-only boilers.

The share of electricity that is used for the cooling of buildings, which is a low exergy demand, is unknown. This share will change based on the building function. For example, data centers have higher cooling loads that can range between 25% to 37% of the total energy usage [27] or about 50% to 74% of the electricity load. Considering the different building functions, as a campus average, 25% of the electricity load may be used for space cooling purposes. In addition, the three buildings with ATES also use these units to reduce the electric cooling load [15, 17]. In these buildings, the respective share was assumed to be 15% of the electricity load.

Equation 5 provides the means of finding the value of the parameter ψ_{Ri} as a weighted average of the relevant values in Table 3 and the associated energy shares based on s_x from s_1 to s_x where x is the number of technology options. The calculated values of the parameter ψ_{Ri} at the building level are given in Figure 9. The campus average that is given in the red line is $\psi_{Ri} = 0.42$.

$$\Psi_{Ri} = \left(\sum_{s=1}^{x} s_x \times \Psi_{Ri} \times E_T \right) / E_T \qquad (5)$$

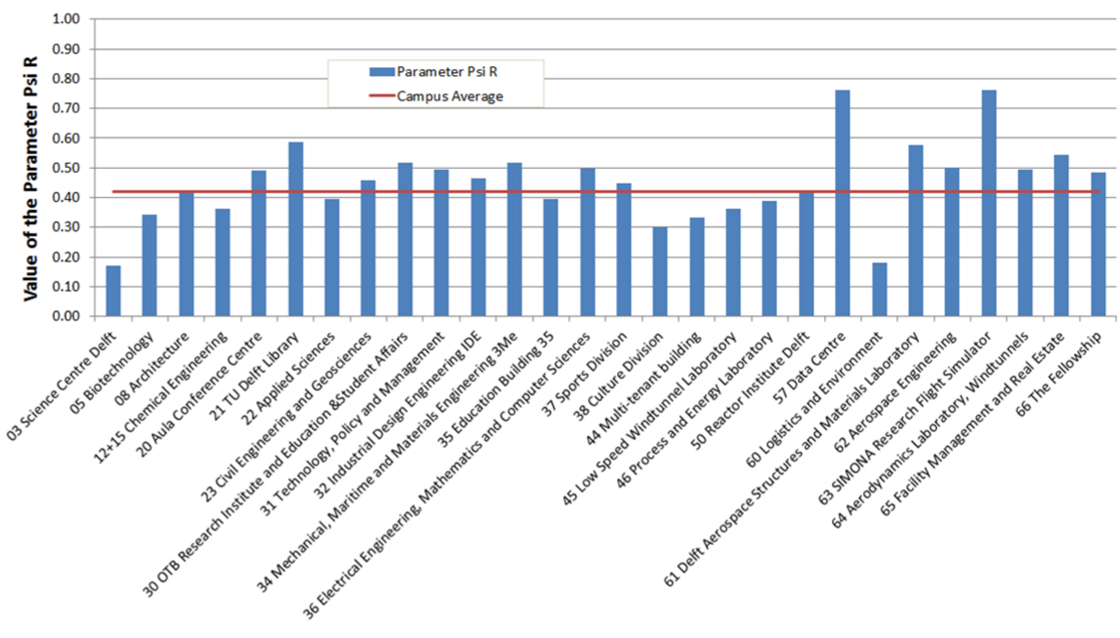


Figure 9. Values of the Parameter ψ_{Ri} for Buildings (Bars) and Campus Average (Line)

Based on Equations 4 and 5, Figure 10 provides both the reported CO_2 emissions (lower bars) and the avoidable CO_2 emission impacts that persist in the energy system based on the parameter ψ_{Ri} (upper bars) per building. The proportion between the two components change based on ψ_{Ri}.

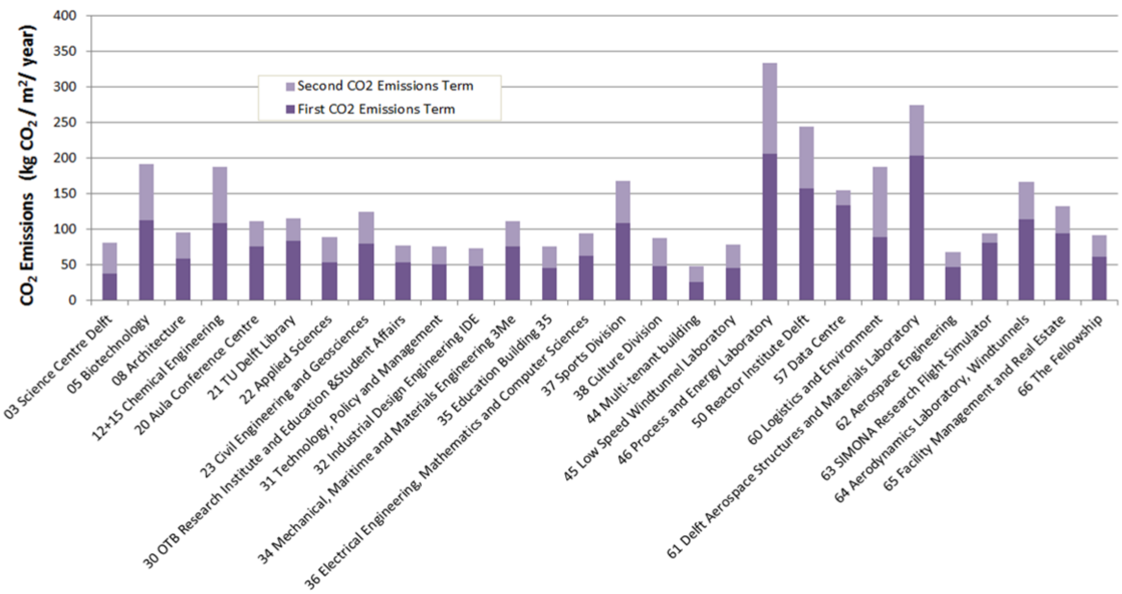


Figure 10. Compound CO_2 Emissions at the Building Level

Integration with spatial dimension. Three inputs of data, namely energy, exergy, and compound CO_2 emissions, are integrated with the spatial dimension as depicted in Figure 11. The labels of the buildings in Figures 7-8 were matched to the respective spatial positions. As preparation for this process, the open source 3D buildings feature of the TU Delft campus buildings in Google Earth Pro [28], which were drawn based on the 3D modelling software Google SketchUp [29], were studied. For each building, the 3D building details were used as a reference to custom draw polygons around the buildings that can be color coded according to the analysis results.

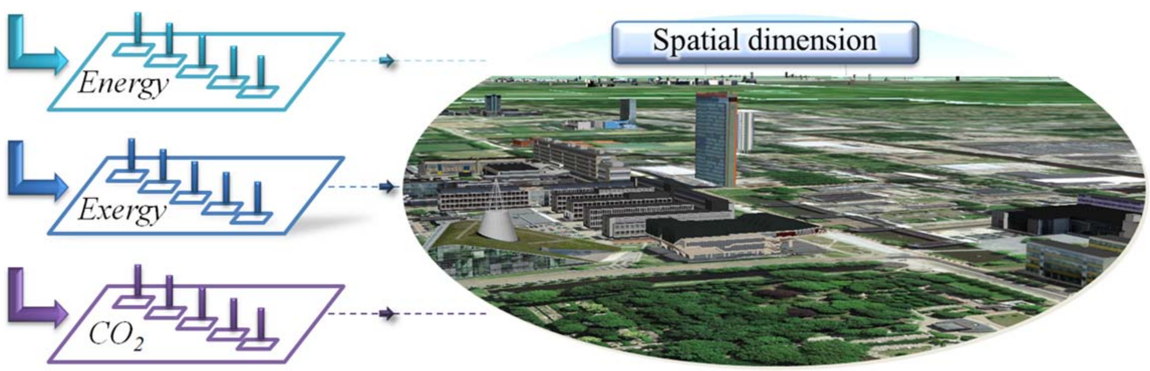


Figure 11. Integration of Data Inputs with the Spatial Dimension

Data analysis

The data analysis is conducted based on the identification of energy, exergy, and CO_2 emissions data with the spatial dimension. The juxtaposition of the different inputs of data at the spatial dimension required principles to represent the data visually on the buildings. These principles were based on methods of comparing and clustering the data and assigning codes to the data groups. The representation of these clusters enabled the mapping of the campus based on the inputs and provided a focus to compare the buildings to each other on a campus-wide landscape.

Campus-wide comparison. The ratio of the total delivered energy E_T in Equation 1 and the total exergy ε_T in Equation 2 provides the average Carnot factor for a particular building. This ratio as given in Equation 6 can distinguish those buildings that use a higher or lower share of high exergy energy resources than others. Figure 12 provides a scatter plot with axes of E_T (horizontal) and ε_T (vertical axis). The 45° line represents the condition $E_T = \varepsilon_T$ or $CF = 1$. The distance of the individual data points from the line is proportional to the value of CF in Equation 6. Based on the histogram on the left top inset in Figure 12, the data points are grouped into bins with intervals of 0.05. The grouping does not necessarily follow the magnitude of the energy or exergy spending. For example, the red data points, which represent the SIMONA Research Flight Simulator and Data Center, uses entirely electricity that has a $CF = 1$. The building has a high exergy spending relative to other buildings. The grey dot is the average value of both axes.

$$CF = \varepsilon / E_T \tag{6}$$

Scenario comparison. According to the analysis method, scenarios for possible changes in the campus energy landscape over time were considered. Table 4 provides the variables in the four scenarios. In each scenario, values of the present status of energy usage in the campus buildings were applied multipliers according to the scenario definition. The application of the scenarios to the spatial mapping enabled a visual representation of the possible changes over time given that one of the scenarios is implemented. These scenarios are also important given the targets of the campus to reduce energy usage and increase the share of renewable energy by the year 2020.

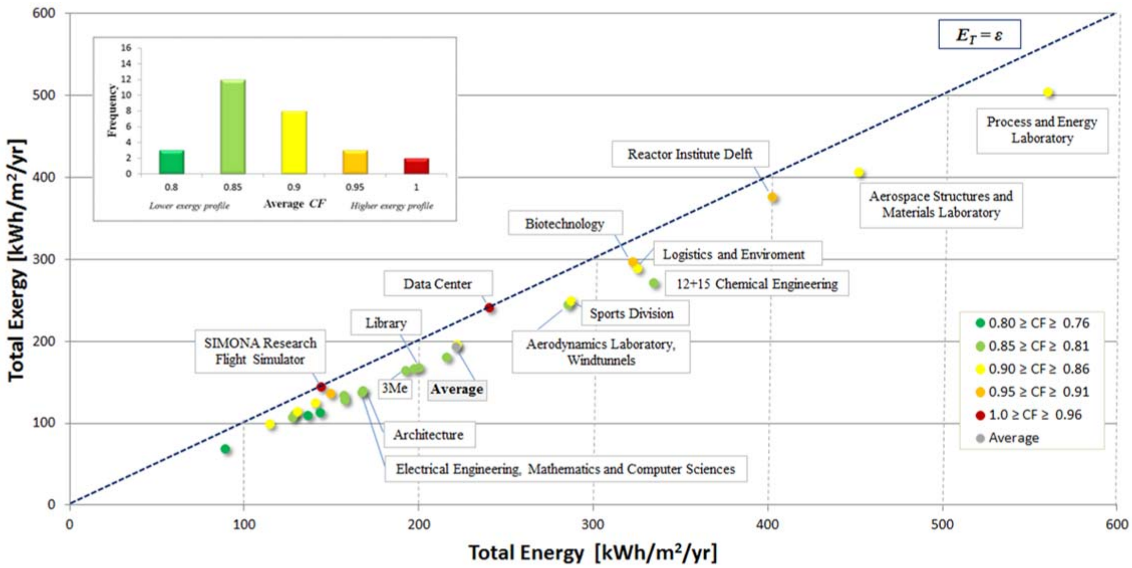


Figure 12. Scatter Plot of the Total Energy and Exergy of Buildings and *CF* Groupings

Table 4. Definition of Five Scenarios to Assess Possible Changes in the Energy Landscape

Scenarios	Variable /Scenario Description	Present Value	Scenario Value
Scenario 1	Energy savings in campus buildings • *Diffusion of energy saving measures to reduce electricity usage by 10% and thermal energy by 15%*	-	10% (E_L) 15% (E_H)

Scenario 2	Electricity load with reduced electric cooling • *Increased supply from CHP in summer mode for the use of waste heat with absorption cooling*	25%	10%
Scenario 3	Share of CHP contribution in the heat network • *Increased share of CHP in the heat network*	25%	50%
Scenario 4	Share of heat-only boilers in the heat network • *Substituted with the use of geothermal energy in a lower temperature distribution network*	75%	40%
Scenario 5	Reduction in CO_2 emissions from electricity usage • *Increased share of wind, solar and bioenergy from on-site renewable energy projects on campus*	-	20%

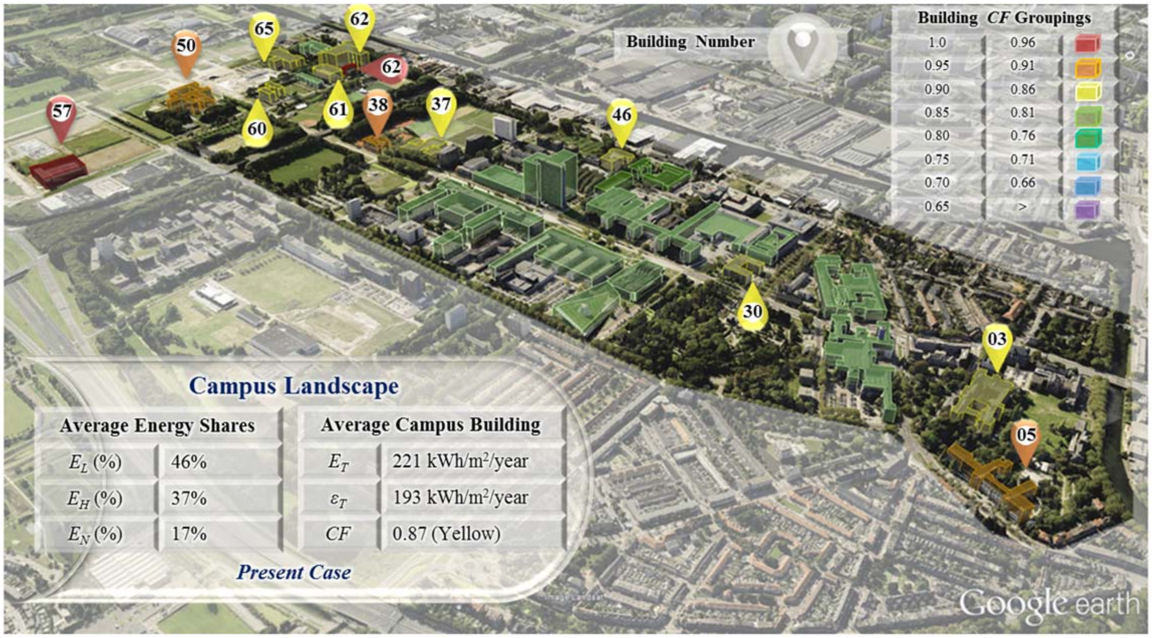
The first scenario is based on the diffusion of measures to capture additional energy savings on campus in the immediate, near term. These savings are a modest representation of the full energy savings potential. In the second scenario, the existing CHP units are used in a summer mode to reduce the use of high exergy electricity for purposes of cooling in buildings that is a low exergy demand. This scenario is represented by reducing the high exergy electricity load of the respective buildings by 15%. The reduced amount is shifted over to the CHP units in which the waste heat is used based on absorption cooling. Initially, this change is restricted to buildings that are connected to the heat distribution network. In addition, the 7 buildings that are not connected to the network are included in another possible variation of this scenario.

The next three scenarios propose other changes in the heat distribution network of the campus. The second scenario modifies the existing high temperature heating network based on a 25% increase in the share of the CHP, which is accompanied by a lowering of the share of heat-only boilers by the same amount. In the third scenario, a second heat distribution network with a lower supply temperature is introduced that is based on geothermal energy. The campus already has plans for such a change based on a partnership with commercial partners [30]. In the last scenario, the campus is envisioned to increase the deployment of on-site renewable energy for electricity generation by 20% based on wind, solar, and/or bioenergy. The progression of scenarios follows a focus on energy savings and increases in the use of renewable energy.

Currently, all scenarios are tested on a separate basis. In the future, different variables in the scenarios as given in Table 4 can be mixed and matched for other desired normative futures. It is also possible that multiple scenarios are arranged across the time dimension starting with energy savings, the optimized use of waste heat, and the maximization of renewable energy. Table 5 provides the results of the application of the scenarios on the spatial dimension.

Table 5. Results from the Spatial Exergy Mapping for TU Delft Campus Buildings

Present Case



Scenario 1

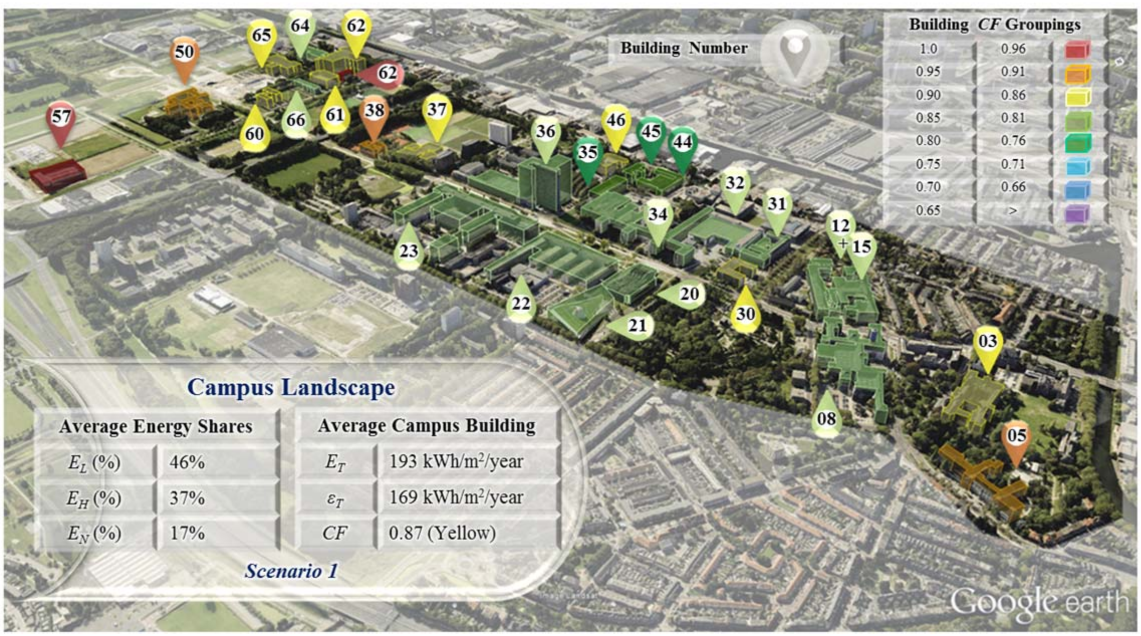


Table 5. Results from the Spatial Exergy Mapping for TU Delft Campus Buildings (Cont.)

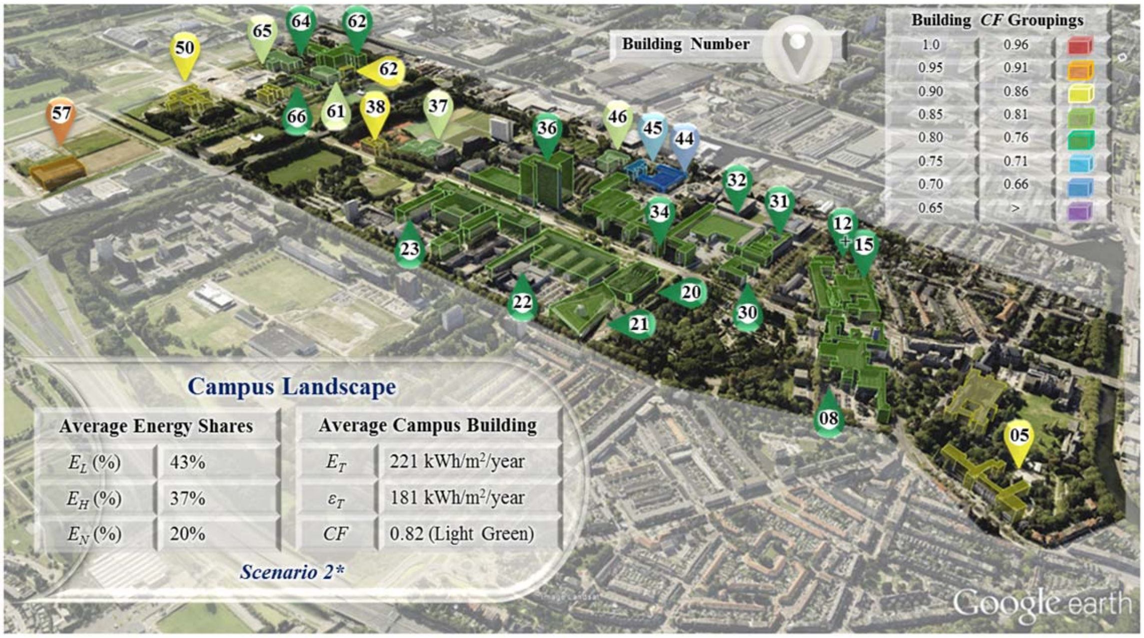
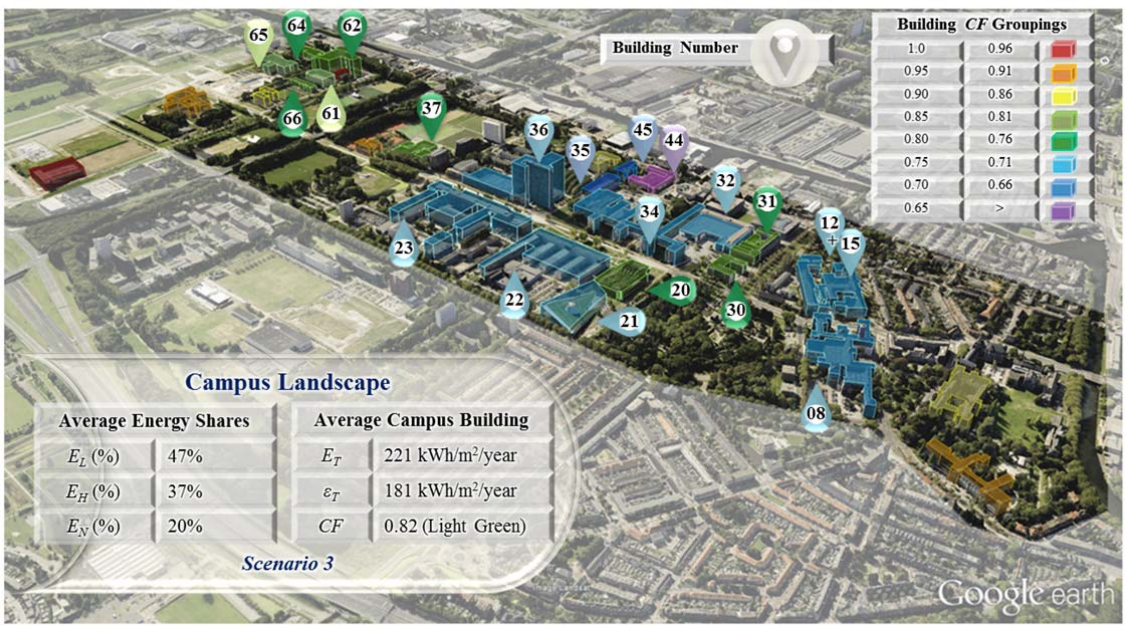
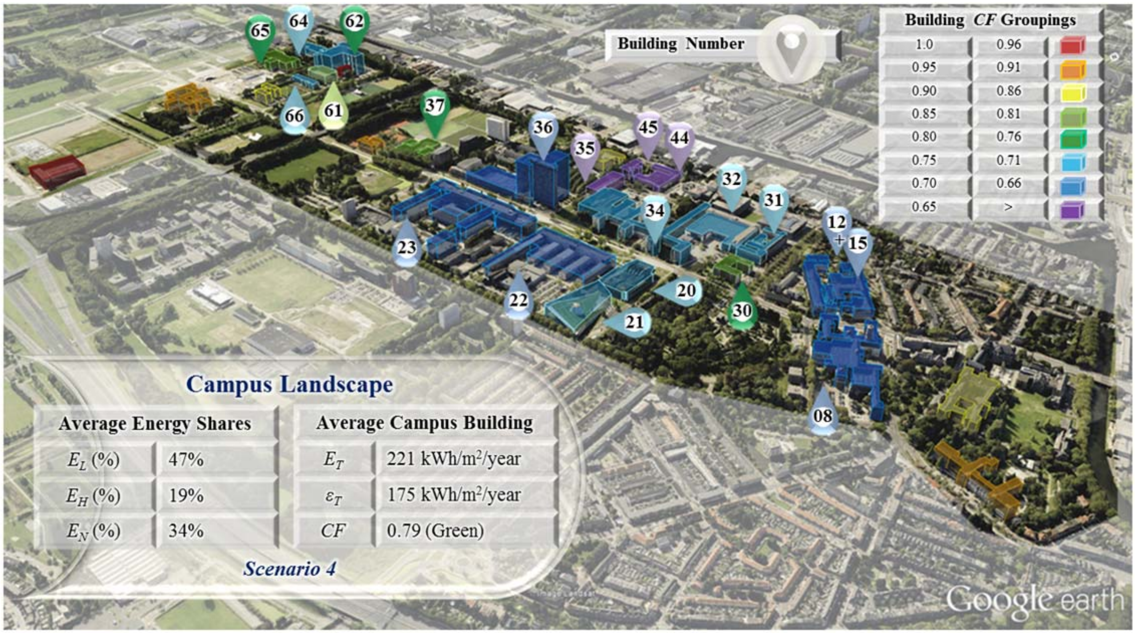
Scenario 2

Scenario 3


Table 5. Results from the Spatial Exergy Mapping for TU Delft Campus Buildings (Cont.)

Scenario 4



3.2 Case Study: *Energy/Exergy Analysis of Building Clusters at KTH and Albano District*

The second case study is based on building clusters at the KTH Royal Institute of Technology in Stockholm, Sweden. KTH is the first polytechnic of Sweden and one of Scandinavia's largest higher education institutes in technology. KTH also adopted the *Vision 2027* strategy document that outlines the overall objective of the campus environment to be embodiments of bold and sustainable urban design as one of Europe's most sustainable technical universities [31-32]. In addition, the university is a member of the International Sustainable Campus Network (ISCN). Accordingly, KTH implements a Sustainability Charter [33] in which the campus reports on the sustainability performance of buildings. In 2014, the KTH campus as a whole used 68,360 MWh of energy [33] that resulted in an average of about 258.5 kWh of energy usage per m^2 of floor area per year considering all campus buildings. This represented a 14% reduction from the level of energy usage in 2012 that was 79,078 GWh [33]. Most recently, KTH was also the recipient of the 2015 ISCN Campus Excellence Award for its campus master planning based on 32 projects [34]. These include plans to establish a CO_2 neutral campus development in the Albano district of Stockholm [35].

Furthermore, the state-owned enterprise Akademiska Hus that owns and manages most of the buildings that Swedish universities use, including KTH, targets to reduce campus-wide energy purchase at supplied energy per m^2 by 50% between 2000 and 2025 [36]. The ability to reach this goal requires KTH to increase the pace of energy savings to about 4% per year [36]. Existing projects to reduce energy purchases include the use of a heat pump system for central heat recovery from servers, the survey of roof space on campus that is suitable for the placement of solar panels, and projects that reach below Swedish building code benchmarks [33]. Such a context makes the campus an ideal platform to analyse building energy usage.

Energy data collection and processing

Data for the KTH campus was collected at the building level for a selected number of buildings and at the energy system level. The collection of data at both levels enabled a broadening and deepening of the analysis at the same time. The building level data made it possible to differentiate the various energy profiles based on the diverse functions of the buildings in providing educational, research, administrative, and other services to the campus community. The energy system level data made it possible to enlarge the scope of analysis beyond the campus into the energy system, including the district heating and cooling network. The approach is also in line with the integrated energy system perspective that is vital for modelling [37].

Selection of the Building Cluster. Akademiska Hus is in the process of making building level data available to the university administration based on an Energy Portal [13]. Currently, data on the monthly purchased electricity of 41 buildings on the main and related campuses of KTH is available in this portal. For the selection of buildings that will be included in the building cluster for the analysis of this paper, the annual purchased electricity per m^2 of floor space for the most recent year (2014) was calculated per building and grouped into categories by building function.

Figure 13 shows the annual purchased electricity of 39 buildings that satisfy different building services, including as faculty buildings and laboratories. The various averages for the different categories of buildings are provided as marked within Figure 13. For example, faculty buildings, which represent mixed used buildings with offices, lecture rooms, laboratories, and kitchenettes, purchase an average of 118 kWh/m^2/year. Such a value is about the average of the electricity purchase of laboratory buildings at 174 kWh/m^2/year and office buildings at 65 kWh/m^2/year. Faculties that may be more equipment intense have a higher electricity purchase, e.g. the Mechanical Engineering buildings. A similar situation appies to laboratory buildings, such as the Chemstry buildings. Buildings in the "other" category, which includes the KTH Library, the restaurant, and other buildings that provide a series of specialzed services to the campus community, have a more diverse range of values. In contrast, the IT/Data Center and a storage building are excluded from Figure 13 since these buildings represent outliers with purchased electricity at over 1,500 kWh/m^2 and less than 5 kWh/m^2, respectively. As the average for the 39 buildings that are included in Figure 13, the purchased electricity was 101 kWh/m^2 per year.

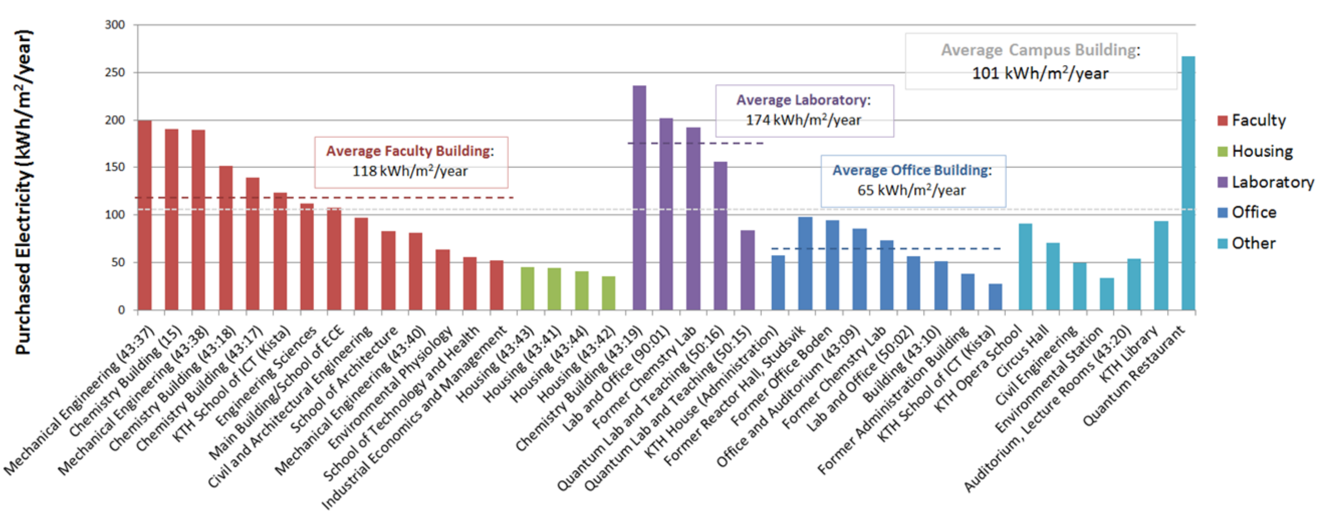


Figure 13. Annual Purchased Electricity per Square Meter per Building and Category

Figure 13 was used to support the original intent of the research work to select buildings with diverse energy profiles. Accordingly, a cluster of 8 buildings was selected from the different building categories. The Civil and Architectural Engineering building, also known as Bergs, and the Mechanical Engineering building (43:38) were selected as faculty buildings that provide mixed mode building services. One of the Chemistry Buildings (43:18) that has laboratories and was made to receive the waste heat of the IT/Data Center before the system was integrated into the campus heat distribution network was also included in the building cluster. In addition, the Sing-Sing building that hosts the Department of Industrial Economics and Management as well as lecture rooms and has an atrium that is used for campus events is also included. As buildings that provide specialized building services, the Library, the IT/Data Center, the new location of the university administration, namely the KTH Huset, and the Quantum Restaurant are further integrated into the building cluster. The Quantum Restaurant is indicated to have the highest purchased electricity among all of the buildings included in Figure 13 after the IT/Data Center.

Data Collection for the KTH Building Cluster. In the future, the Akademiska Hus Energy Portal is expected to provide building level data on the purchase of thermal energy, including heat and cold from district heating and cooling, which is currently missing. For this reason, the buildings that were selected for inclusion in the building cluster, which was limited in number as requested by Akademiska Hus officials, were submitted for additional data request. Based on the request, the operational reports of the buildings for the most recent year, namely the "Driftrapport uppföljningsområde" reports, were obtained, which contained monthly energy purchase data for electricity, district heating, and district cooling. The values for the purchased amount of district heating were climate corrected. The purchase of hot water was not consistently available for all buildings. As a result, the purchase of hot water was not included in the overall analysis. Figure 14 provides the graphs of the compiled data for the 8 buildings in the KTH campus cluster.

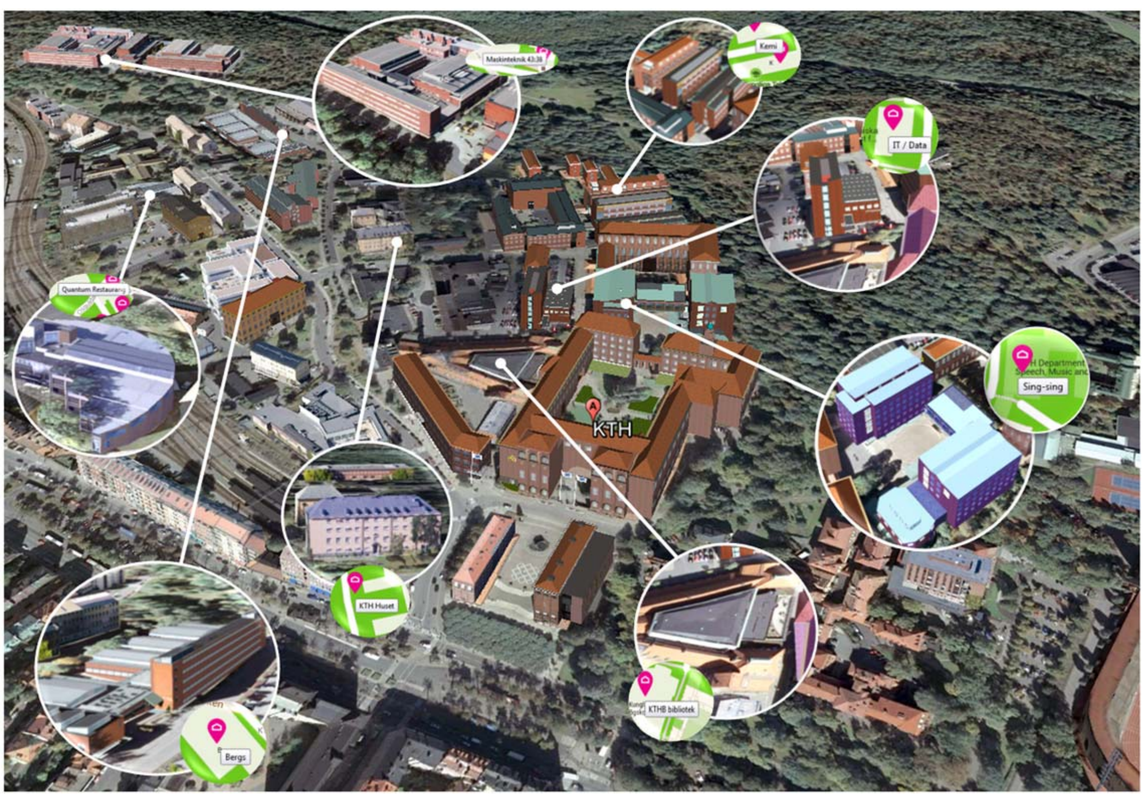
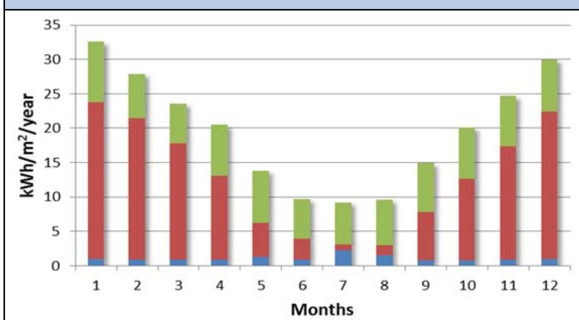
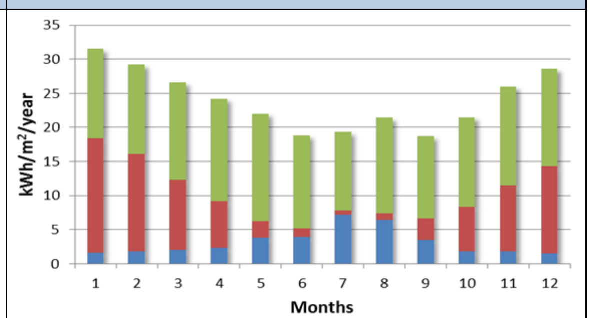
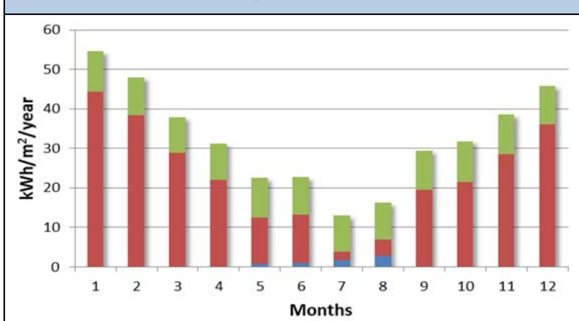
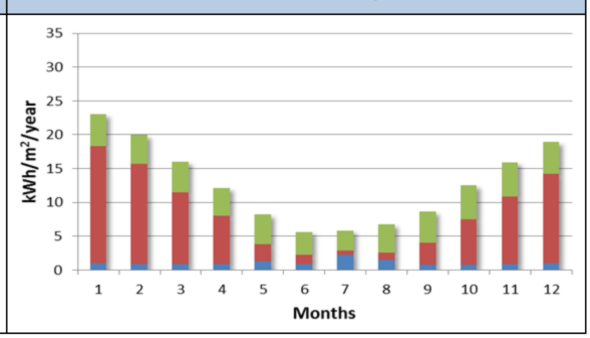


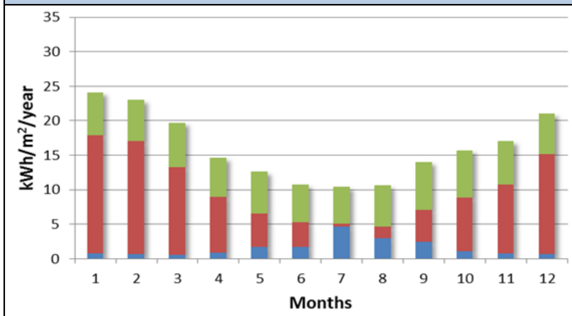
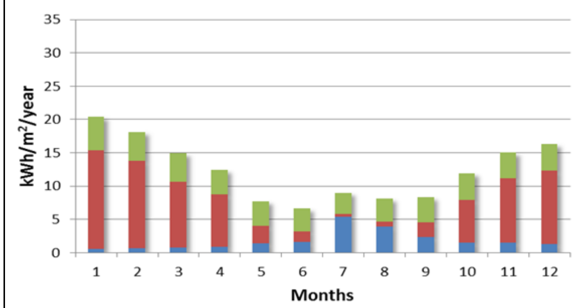
Figure 14. Selected Buildings for Inclusion in the KTH Building Cluster

The compiled data in Table 6 indicates the differences in the energy profile of the buildings in the cluster. Among the faculty buildings, Civil and Architectural Engineering has a higher district heating purchase at 139.4 kWh/m^2/year than Mechanical Engineering. In contrast, Mechanical Engineering, which has a relatively higher share of laboratory equipment, has a higher district cooling purchase year round and a higher electricity purchase. The Chemistry building has the highest district heating purchase at 268.8 kWh/m^2/year as well as the lowest district cooling purchase at 6.5 kWh/m^2/year among the buildings in the sample cluster. The Sing-Sing building has a similar district heating purchase as the Mechanical Engineering building at 88.3 kWh/m^2/year and an electricity purchase similar to KTH Huset.

The KTH Library, which was awarded the Helgopriset Prize for the restoration of existing buildings [38], has a district heating purchase that is closest to the average value in the building cluster at 101.5 kWh/m^2/year. The IT/Data Center has the lowest district heating purchase at 51.9 kWh/m^2/year but the highest district cooling and electricity purchase due to the function of being a data center. Another feature of this center is that the cooling usage is relatively steady year round for a total of 1,504.5 kWh/m^2/year purchase of district cooling. The Quantum Restaurant also takes place among those buildings with a relatively stable purchase of district cooling annually but at a lower magnitude, i.e. 65.5 kWh/m^2/year. Including the IT/Data Center, an average building in the cluster purchases 113.1 kWh/m^2 of district heating, 210.2 kWh/m^2 of cooling, and 303.0 2 kWh/m^2 of electricity per year.

Table 6. Purchased Electricity, District Heating and District Cooling Characteristics

Civil and Architectural Engineering (Bergs)	**Mechanical Engineering Building (43:38)**
	
• Season thermal energy peaks (heat/cold) • Relatively stable electricity purchase	• Higher district cooling purchase year round • Electricity purchase is relatively higher
Annual Energy Profile (kWh/m^2/year)	*Annual Energy Profile* (kWh/m^2/year)
□ E_H: 139.4 □ E_C: 13.1 □ E_L: 84.1	□ E_H: 85.7 □ E_C: 37.6 □ E_L: 164.5
Chemistry Buildings (43:18) *	**Industrial Economics Management (Sing-Sing)**
	

<table>
<tr><td colspan="3">Significantly higher district heating purchase
Minor cooling, stable electricity purchase</td><td colspan="3">Season thermal energy peaks (heat/cold)
Relatively stable electricity purchase</td></tr>
<tr><td colspan="3">Annual Energy Profile (kWh/m^2/year)</td><td colspan="3">Annual Energy Profile (kWh/m^2/year)</td></tr>
<tr><td>□ E_H: 268.8</td><td>□ E_C: 6.5</td><td>□ E_L: 116.3</td><td>□ E_H: 88.3</td><td>□ E_C: 13.1</td><td>□ E_L: 51.9</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="3">KTH Library</td><td colspan="3">KTH Huset</td></tr>
<tr><td colspan="3">
</td><td colspan="3">
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<tr><td colspan="3">Lower district heating and cooling purchase
Relatively stable electricity purchase</td><td colspan="3">Lower heating, similar cooling purchase
Relatively stable electricity purchase</td></tr>
<tr><td colspan="3">Annual Energy Profile (kWh/m^2/year)</td><td colspan="3">Annual Energy Profile (kWh/m^2/year)</td></tr>
<tr><td>□ E_H: 101.5</td><td>□ E_C: 19</td><td>□ E_L: 72.9</td><td>□ E_H: 80.1</td><td>□ E_C: 21.9</td><td>□ E_L: 46.7</td></tr>
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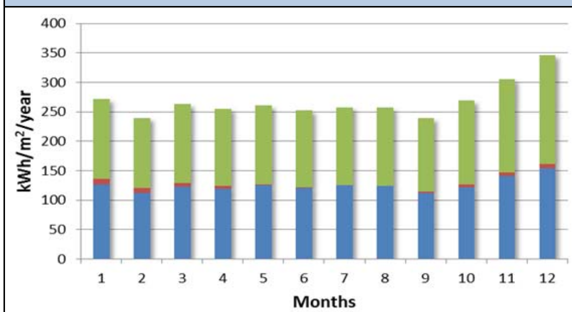
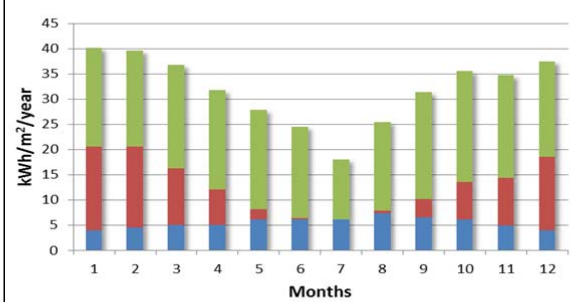
<tr><td colspan="3">IT/Data Center *</td><td colspan="3">Quantum Restaurant *</td></tr>
<tr><td colspan="3">
</td><td colspan="3">
</td></tr>
<tr><td colspan="3">District cooling purchase is high but steady
Highest electricity use per m^2 on campus</td><td colspan="3">Relatively high but steady cooling purchase
Second highest electricity purchase per m^2</td></tr>
<tr><td colspan="3">Annual Energy Profile (kWh/m^2/year)</td><td colspan="3">Annual Energy Profile (kWh/m^2/year)</td></tr>
<tr><td>□ E_H: 51.9</td><td>□ E_C: 1,504.5</td><td>□ E_L: 1658.8</td><td>□ E_H: 89.9</td><td>□ E_C: 65.5</td><td>□ E_L: 228.6</td></tr>
</table>

* Indicates buildings with different y-axis scales above 35 kWh/m^2/year to accommodate value differences

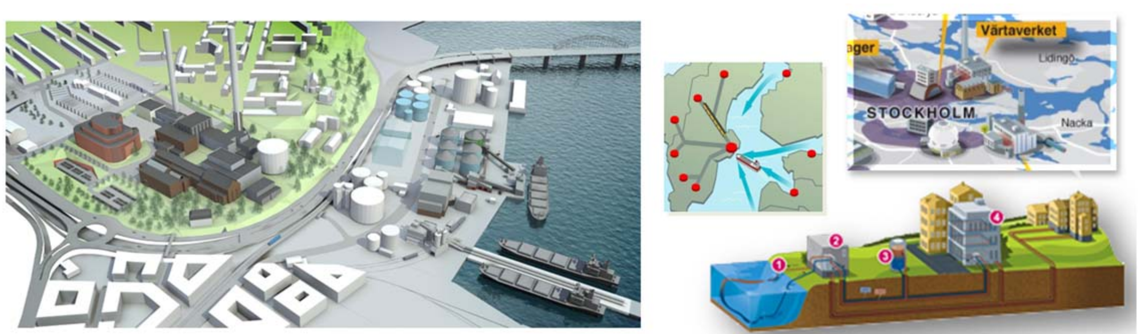
The Swedish Building Code (BBR) [39] indicates values for the specific energy use of residential and commercial buildings. Table 7 summarizes the values in the BBR for the specific energy use of commercial buildings when the method of heating is other than electric heating. Buildings that use electric heating are provided with other values. Stockholm is in climate zone 3 with a value for specific energy use at 70 kWh/m^2. Buildings can receive a supplement in these upper bounds per m^2 when the floor area is greater than 130 m^2 [40]. For buildings to be certified under the scheme of the Environmentally Classified Building, namely Miljöbyggnad, specific energy use must be less than a factor of 1, less than a factor of 0.75, or less than a factor of 0.65 to rank as bronze, silver, and gold, respectively [41].

Table 7. Swedish Building Code Values for Building Specific Energy Use [39]

Building specific energy use	**BBR Value (kWh/m^2 year)**			
	Zone 1	*Zone 2*	*Zone 3*	*Zone 4*
Buildings that have other heating means than electric heating	105	90	70	65

The aim of Akademiska Hus is that all new buildings must at least meet the requirements for Miljöbyggnad Silver [36]. Most recently, the new course and office building at the School of Architecture and the Built Environment (ABE) received Miljöbyggnad Gold based on energy savings that are 65% less than the BBR building code [36]. In addition, one remodelling project at the KTH campus was awarded Miljöbyggnad Silver [36]. Another project to construct a new, 5-storey building for offices and seminar rooms for ABE is planned to receive Miljöbyggnad Gold once completed in 2017 [42]. The new building will also have solar panels that will be part of a larger effort to integrate solar panels within the campus.

Data Collection for the Energy System. The Värtaverket combined heat and power plant (CHP) is located in the east of the Hjorthagen district of Stockholm that is about a 2.5 km distance from the main KTH campus. In addition to CHP units, two heat pump stations nearby at Ropsten and Nimrod provide additional heating and cooling as needed based on the seawater at Lilla Värtan. Based on the outputs of the CHP plant and heat pumps, central Stockholm has one of Europe's largest district heating and cooling systems. The heat distribution grid has a total length of about 330 km and produces enough heat to cover the heating needs of about 140,000 houses a year [43]. The energy customers include the KTH campus and other buildings in central Stockholm. Figure 15 provides a rendering of the Värtaverket CHP facilities and Ropsten heat pumps.



Värtaverket CHP Units **Seawater based Heat Pumps (Ropsten)**

Figure 15. Representation of the CHP facilities (left) and heat pumps (right) based on Ref. [44]

In a typical year, Värtaverket produced 4,530 GWh of energy [45]. Of this total, 3,287 GWh of heat and 313 GWh of cold were provided to the district heating and cooling (DHC) grid. A total of 930 GWh was provided as electricity. Table 8 provides the design capacities of the units in the Värtaverket CHP plant, including the heat pump stations. Table 8 also provides the shares of the units in the total district heating capacity and the realized share of each unit in a typical year. CHP (47%) and the heat pumps (21%) have a dominant share in the district heating grid. The peak load boilers and electric boilers provide the remaining contribution to the district heating grid. In the district cooling grid, the heat pumps have a 100% share as indicated in Table 8.

Table 8. Technical Specifications of the Värtaverket Facility Based on Refs. [45-46]

Värtaverket CHP Plant Facility	Maximum Capacity (MW)			Share in Total DH [a]	
	E_H	E_C	E_L	Capacity	Realized
Existing CHP unit KVV6	310	0	145	0.18	0.47
Bio-oil fired CHP unit KVV1	320	0	190	0.18	
New biofuel CHP units (KVV8) [24]	280	0	130	N/A	N/A
Water based heat pumps Ropsten 1, 2 &3	250	110	0	0.14	0.21
Water based heat pumps Nimrod	36	48	0	0.02	
Peak load boilers	620	0	0	0.35	0.19
Electric boilers	230	0	0	0.13	0.13
Gas turbine	0	0	54	0.00	0.00
Total (Existing) [b]	**1766**	**158**	**465**	**1.00**	**1.00**

[a] Based on capacity data and realized district heating share data in Refs. [45-46]
[b] Does not include the new biofuel CHP units (KVV8) to be commissioned in January 2016

Figure 16 provides a simplified schematic of the main energy conversion processes based on the input of biofuels, coal, and other sources, such as electricity. The facility has a shipport and is located near the train station to minimize the impact of transport based on the use of boat and rail, including for biomass [46]. In the near future, the share of renewable energy will increase above 70% based on the new biofuel based CHP plant KVV8 that will be installed in addition to the existing units KVV6 and KVV1 [46]. The installation is also indicated to assist the targets of the city of Stockholm for becoming fossil-fuel free in the long term by the year 2050 [47].

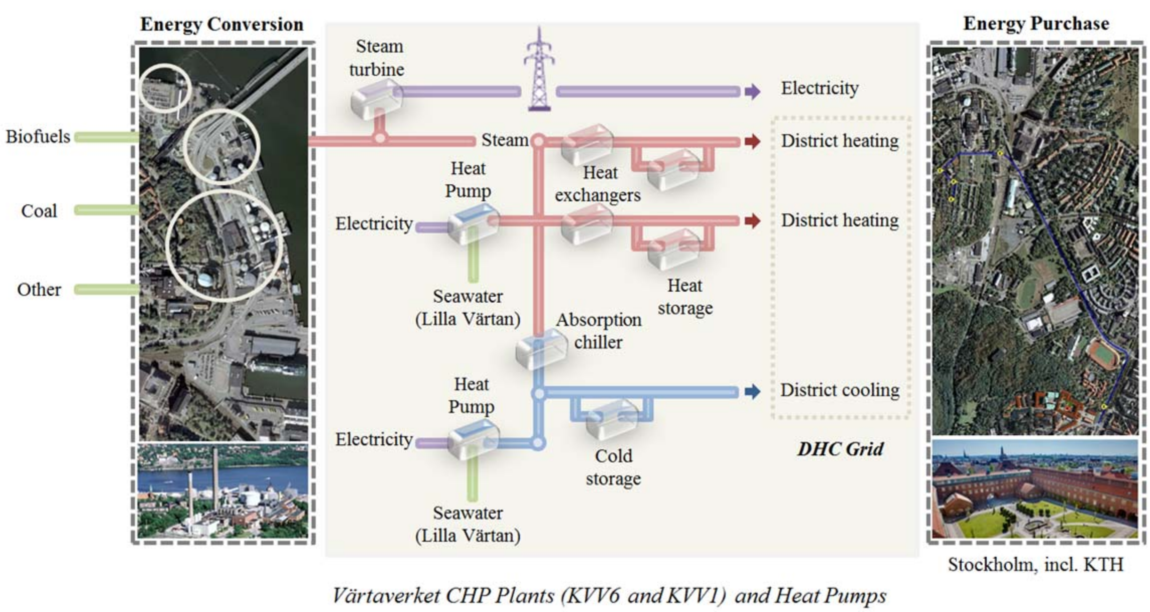


Figure 16. Schematic of the Värtaverket CHP Plant that Services the KTH DHC Substation

In the Värtaverket site, the mean value for the supply temperature in the flow conduit is about 82 °C (355 K) and the return temperature in the return conduit is about 44 °C (317 K) [48]. These values confirm with the target of having the return temperature be lower than 50 °C (323 K) on the KTH campus. The owner of the Värtaverket CHP Plant and the supplier of the DHC grid Forum charges the campus with a higher price if the return temperature is 60 °C (333 K) or higher [49]. This provides an incentive to purchase and utilize the heat more rationally.

In the summer, heat pumps based on seawater intake from the sea bed at 4°C (277 K) supplies the buildings with chilled water at about 6°C (279 K) that returns back to the facilities at about 16 °C (284 K) [50]. The heap pumps can operate either as standalone or in parallel or series with waste heat depending on the actual cooling requirements in the Stockholm area [50]. The facility also has an Aquifer Thermal Energy System (ATES) component with 12 wells that increases peak capacity [50]. In the winter, heat pumps are made to benefit from treated waste water [50].

The KTH campus has a central distribution substation behind the KTH Library at the old campus plant, namely Värme- och kraftcentral, which directs the purchased energy from the city DHC grid to the campus buildings. In addition, the Centre for High Performance Computing at the IT/Data Center was installed with a heat pump system that recovers waste heat from the servers based on the need to cool 36,384 central processing unit (CPU) cores [51]. To some extent, the system reduces the energy load to cool the supercomputers [51]. The output of the waste heat recovery was used in the Chemistry buildings until 2014 before being reconnected to the central distribution substation to feed the supply of heat to the campus buildings [52].

Data Collection for the Albano District Buildings. The Albano area, once an industrial site, is located between KTH, Stockholm University, and Karolinska Institute [53]. By the year 2019, the area is expected to start becoming a liveable campus and sustainable urban development with educational facilities (e.g. lecture halls) as well as accommodation facilities for about 15,000 students and guest researchers for the joint use of the three universities [53]. The Albano district is expected to have classrooms and auditoriums with flexible solutions, study carrels and group workplaces for students, and new research environments [53]. The main entrance of the campus will be located in front of the existing AlbaNova campus. In addition, some of the buildings are envisioned to produce as much heat and electricity as consumed on an annual basis with hybrid energy systems [53]. The proximity of housing and educational facilities is also expected to reduce CO_2 emissions [53].

As a future urban development project, there are limited projections for energy usage at the building level. The most available source of estimated energy data is for the southern part of the first phase of the construction process with a cluster of 10 buildings with a total floor area of 98,000 m^2 [54]. In this cluster, 5 of the buildings with a floor area of 60,000 m^2 are expected to be for lecture purposes and 5 of the buildings for residential uses. The specific energy data estimates for electricity, heating, and cooling are given in Table 9 based on Ref. [54].

Table 9. Estimated Energy Usage by Building in the Albano District (Based on Ref. [54])

Building Function	***Specific Energy Profile* (kWh/m^2/year)**			**Total Floor Area (m^2)**
	E_H	E_C	E_L	A_T
• Lecture	23	8	32	60,000
• Residential	19	0	54	38,000
Average	22	5	40	98,000

Comparison of Building Data by Function. Based on the empirical data for buildings in the KTH cluster, the purchased electricity, heating, and cooling was weighted with the total floor area of the buildings to obtain average values by building function. Equation 7 provides the approach for finding these average values. Here, E_H is the purchased energy from district heating, E_C is the purchased energy from district cooling, E_L is the purchased electricity, and E_T is the total purchased energy. A_b is the floor area of each building in the category of the relevant function that is being considered from b =1 to x. A_T is the total floor area in the category. These values were calculated and compared to the estimated energy profile of the Albano building cluster.

$$E_T = \left(\sum_{b=1}^{x} A_b / A_T \right) \times \left(E_H + E_C + E_L \right) \tag{7}$$

In addition to a comparison by similar building function in the two clusters of KTH and the Albano district, Figure 17 provides a collective comparison of all buildings based on the annual energy usage per m^2 by energy component, i.e. purchased district energy, district cooling, and electricity. The IT/Data Center is given separately since the axis values are significantly different. Figure 18 provides a collective comparison of all buildings from an exergy point of view. There is a downscaling of magnitude in the exergy values since the energy values, except electricity, are multiplied by *CF* less than 1.0. Buildings that use less electricity have a more significant downscaling, e.g. Chemistry building. At the energy system level, Figure 19 provides the results of the level of match in the supply and demand of exergy for the CHP and the district heating and cooling grid. Based on the shares of the technologies that provide a value of the parameter ψ_{Ri} at 0.49, the avoidable CO_2 emissions impact per unit of energy in the present case is 0.06 kg CO_2 per kWh. One of the motivations of the scenarios is to reduce this impact.

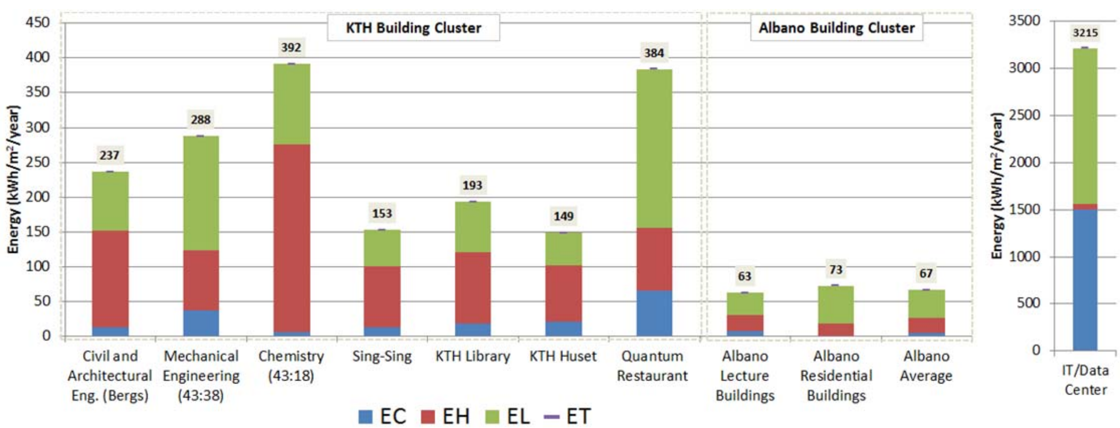


Figure 17. Comparison of the KTH and Albano Clusters based on Energy (Present Case)

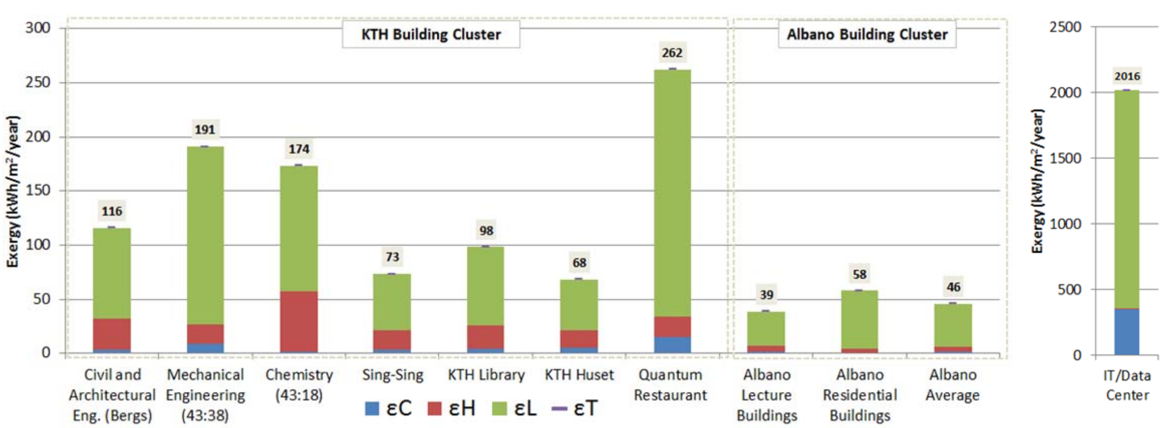


Figure 18. Comparison of the KTH and Albano Clusters based on Exergy (Present Case)

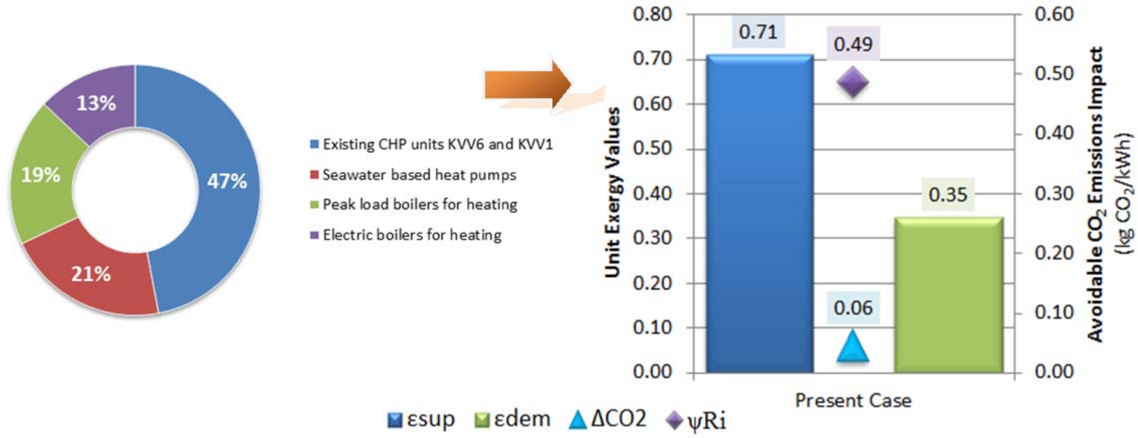


Figure 19. Shares in the Energy System (Left) and Exergy Profile of the Present Case (Right)

4. Implications for the Net-Zero Exergy District Planning of Östra-Sala backe

EULF aims to address different scales in the application of spatial energy data for policies with scopes ranging from the building and urban context up to the member state and European levels [11]. Similar to this aim, this contribution also aims the process of scaling-up the best practices of spatial data acquisition for university campuses and building clusters to the urban district level and in particular, a special form of urban district based on the target of net-zero exergy district (NZEXD). According to the definition, a district is a NZEXD if and only if the annual consumption of energy is less than or equal to the production of energy at the same grade or quality level [7]. The Östra Sala backe district project is in the process of being planned to meet the NZEXD target as analyzed in Refs. [8-9]. Table 10 provides the phases in the planning process based on a total of four main phases. The integration of a building and/or building cluster spatial dimension can further support the aims of the project.

In addition, Figure 20 depicts the process of scaling-up best practises from the scale of a single building to the scale of a pilot district or its sub-component (e.g. phase one) and to the level of an extended district (e.g. phase two) all the way to an entire district and/or city. These best practises are referred to as “exergy-green” solutions due to the awareness of bringing together green solutions in an exergy-conscience way that considers the need to secure better exergy matches between the demand and supply. For example, solutions in the first phase all have a high level of exergy match that is measured by the parameter ψ_{Ri}, which is found to be 0.84 [8]. The district is also one of the case studies in the International Energy Agency (IEA) EBC Annex 64 on Optimized Performance of Energy Supply Systems with Exergy Principles [55].

Table 10. Depiction of the Four Phases of the Östra Sala backe Project in Sweden

Visual Representation of Phases 1-4	**Description**
	• Mix of housing types and elements of business premises • Approximately 55,000 square meter GFA (gross total area)
	• Neighborhoods in and around Årsta center with 500 homes • Many of these houses will be zero-energy buildings
	• Mix of housing types and elements of business premises • Public transport interchange is planned at shopping center
	• Mix of housing types and elements of business premises • Southernmost district in the area of development

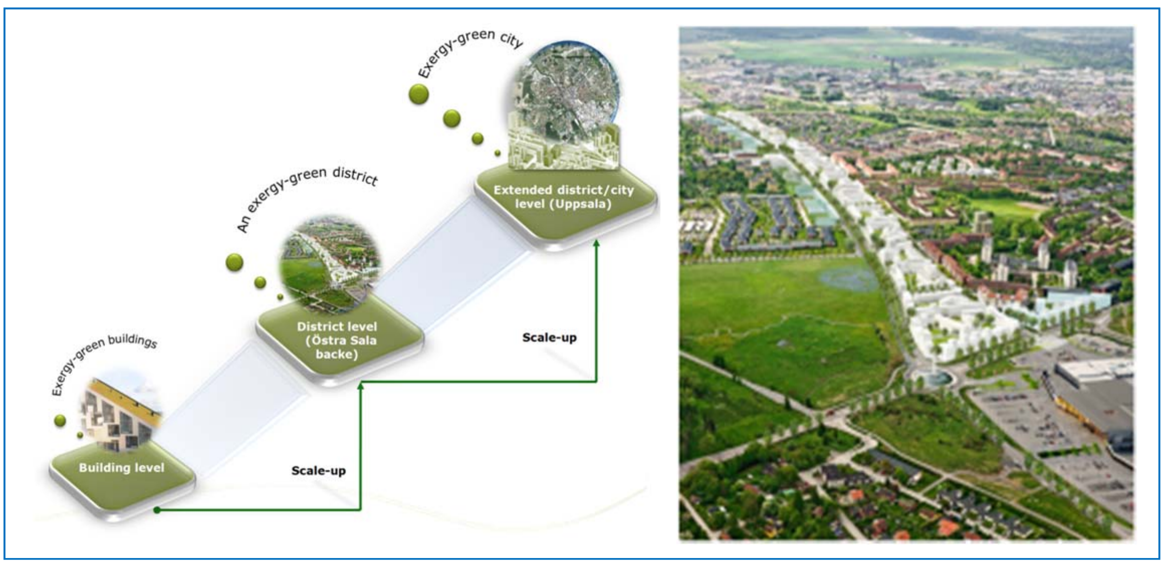


Figure 20. Process of Scaling-Up Best Practises Leading to an Extended District/City Level

In particular, the realization of the CO_2 mitigation potential from an exergy point of view depends on the use of dedicated metrics (e.g. the parameter ψ_{Ri} and the NZEXD target), decision-making algorithms, and scenario implementation. Figure 21 integrates these aims into four key steps that can be implemented in districts in the process of scaling-up best practises towards an exergy transition and realizing the CO_2 mitigation potential of the district. These key steps include modelling of the NZEXD status of the district (step 1), modelling the level of exergy matches and compound CO_2 emissions (step 2), considering scenarios for net-zero statuses for exergy and/or CO_2 emissions (step 3), and selecting a scenario based on the results of the decision-making tools and the initiation of the scenario implementation (step 4).

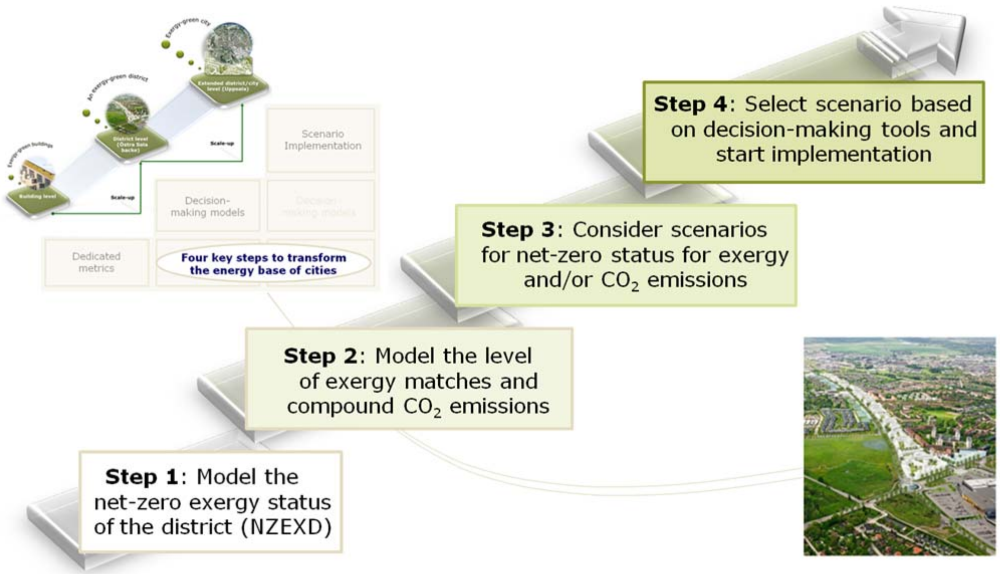


Figure 21. Four Key Steps in the Process of Planning for an Exergy Transition

5. Conclusions for the Use of Spatial Data to Support an Exergy Transition

The integration of location data can support local authorities, such as CoM signatories, in realizing the full potential of planning and implementing energy related measures, including measures to improve the level of match between the supply and demand of exergy. The integration of location data for appropriate indicators, including energy, exergy and CO_2 emissions, can also foster the realization of an "exergy transition" towards a more sustainable energy landscape in the future. The two pilot case studies of this JRC EULF Workshop contribution indicate the means of utilizing location specific data to assess the performance of buildings in university campuses and related building clusters, namely the campus of TU Delft in the Netherlands and KTH in Stockholm. The best practices of these pilot cases also hold potential for the planning of a NZEXD in Sweden, namely the Östra Sala backe project. The indicators that are used in these case studies can be assessed for inclusion in the dashboard of energy indicators in the context of the INSPIRE Directive, especially since the existing Boolean attributes can be used in related calculations. Moreover, an extension to the cities of the campuses or the NZEXD district can provide suitable cases for the EULF pilot project.

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55. IEA ECBCS Annex 64, LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles.

Split of total energy consumption into space heating and domestic hot water usage

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1 Introduction

The energy performance of buildings can be assessed in many ways. As more and more data is collected on the actual energy consumption then it becomes feasible to make more data driven assessments. When using the total energy consumption of a building it is important to acknowledge that it is composed of several components. The two overall components are related to the building envelope and the occupancy behaviour. For labeling the energy performance of a building it is important to consider which components to include - often the interest is in the envelope.

In this paper a method for separating the total heat load into domestic hot water (DHW) heating and space heating is presented. Data from an individual residential building connected to a district heating network in Denmark is used. It consists of a time series of 10 minute values of total heat load, which is the sum of DHW and space heating. DHW is used by the residents for showering, dish washing, etc., and the space heating is used to heat the house. The DHW heating is seen as spikes on top of the space heating. This is due to the fact that showering and dish washing use intense amount of energy for short periods.

The described method for separating the total heat load is quite generic and can therefore easily be used for other applications, where spikes need to be separated from other signals. The separation can be useful for building energy performance estimation based on data ([15] and [10]) and for load forecasting where the presented method was actually used [2]. The separated DHW consumption can be used for example for constructing load profiles for DHW ([18] and [1]), the latter using in-homogeneous Markov chain models providing a fully data-driven stochastic modelling approach. Other important applications are control for heating systems enabling demand response for integration of renewables, for example by using a hot water tank [7] or the building structures [13] for energy storage.

Separating consumption signals into sub-components has been studied quite intensively the last decades, mainly for electrical appliance load monitoring ([8] and [5]). Also residential water consumption dis-aggregation into end-use categories has been studied [12], using high resolution readings (5 sec.). Such methods are more event based where patterns are matched. Methods for spike detection has been studied in-depth for medical applications such as EEG. Several approaches to determining amplitude thresholds are used, for example different statistical approaches [3], and filtering and wavelets [14]. A comprehensive review of different techniques is given by [19].

In the present study a statistical time series approach [11] based on kernel smoothing techniques for time series ([4] and [16]) is applied. These are combined with robust estimation (see [9] and [17]) enabling the separation of the very high spikes to be carried out without interfering with the remaining signal. The idea of the method is to use a non-parametric function to estimate the space heating. The space heating changes during the day and is a low-pass filtered response of mainly the outdoor temperature and the solar radiation, but it also depends on thermostat settings. Consequently, the heating changes over time at frequencies related to those variables and the method is therefore designed such that the non-parametric estimate follows these changes, with limited influence from the spikes, which are significantly higher than this estimate and therefore can be separated as DHW heating.

2 Data

The data used in the study consists of the total heat load of a single-family freestanding residential building with two occupants. Sønderborg District Heating Company located in Southern Denmark delivered the data. The period used is covering one month from 1$^{\text{st}}$ of March to 1$^{\text{st}}$ of April 2010. The data was logged approximately every 10$^{\text{th}}$ minute. The unit of the heating is mega joule per hour [MJ/h]. The total heat load is represented with the time series $\{Q_t, \quad t = 1, \ldots, N\}$, where Q_t is the total heat load at time t and $N = 4607$ is the number of observations in the times series. Figure 1 shows the raw data from this period. Some of the spikes are as high as 160MJ/h and have been cut off by the frame in order to make the lower variations visible. The figure shows that in a two weeks period from Friday 12$^{\text{th}}$ until Friday 26$^{\text{th}}$ there are no spikes and the total heat load has very little variation. It is assumed that the residents were on vacation and left the house during these two weeks. The inclusion of this vacation period provides an opportunity to see the performance of the models in separating the DHW heating from the space heating, since the models should predict that no DHW heating is used during that period.

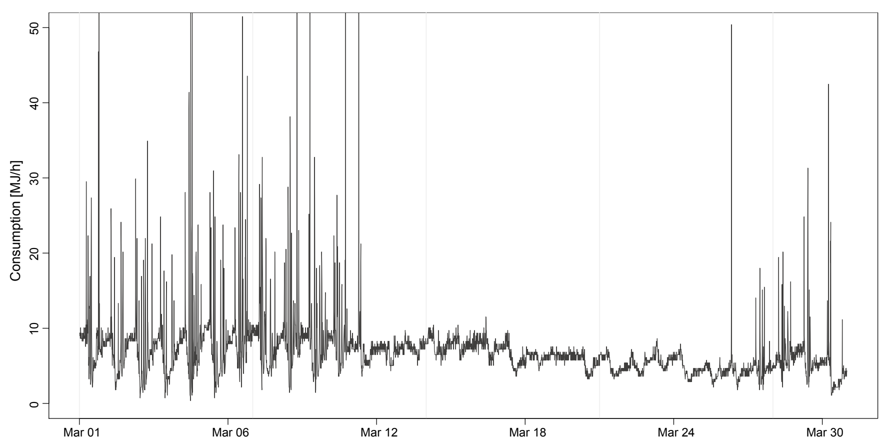

Figure 1: Total energy consumption for March 2010.

3 Results

In the following an ordinary kernel smoother and a robust kernel smoother are presented for separating the DHW and space heating. It is assumed that the spikes represent DHW heating and the remaining signal represents space heating, therefore spikes significantly higher than the kernel smoother estimate needs to be identified.

3.1 Ordinary kernel smoother

A kernel smoother is a method to estimate the underlying function of some relation given noisy measurements. Kernel estimation is a non-parametric estimation technique, where no explicit description of the true function is needed and only a bandwidth parameter needs to be set [16]. The kernel smoother is

$$\hat{g}(t) = \frac{\sum_{i=1}^{N} Q_i k\left(\frac{t-i}{h}\right)}{\sum_{i=1}^{N} k(\frac{t-i}{h})} \tag{1}$$

where $\hat{g}(t)$ is the kernel estimate for a given time t and h is the bandwidth parameter. From the formula it is seen that the kernel smoother is a local weighted average around the given time t, hence a zero order local estimate. The function $k(\cdot)$ is the kernel, which determines how the weight should be put on the neighboring data points. The Gaussian kernel $k(u) = \frac{1}{2\pi}\exp\{-\frac{u^2}{2}\}$ is chosen. The bandwidth h is a smoothing parameter which determine the width of the kernel. As $h \to \infty$ the estimate will go towards the overall mean value $\hat{g}(x) = \bar{Y}$. Therefore for large values of h the kernel estimate will be biased. As $h \to 0$ the kernel estimate would just be equal to the nearest data points and there will be no bias, but a large variance. Hence the bandwidth needs to be tuned for the particular data and in the present case a bandwidth equal to $h = 12$ (Corresponding to 2 hours) is found adequate.

The kernel smoother estimate, $\hat{g}(t)$, is used to separate the total heat load into DHW and space heating. The DHW heating is found by

$$\hat{Q}_t^{\text{water}} = I\left(Q_t > q_{\text{thres}} \cdot \hat{g}(t)\right) \cdot \left(Q_t - \hat{g}(t)\right) \tag{2}$$

where $I(\cdot)$ is the indicator function. Hence spikes above $q_{\text{thres}} \cdot \hat{g}(t)$ are identified as DHW heating and the DHW is found by subtracting the kernel estimate. The separation threshold q_{thres} needs to be tuned according to the local variance of the space heating signal, and such that the DHW usage spikes are significantly higher than this noise level. In the present case $q_{\text{thres}} = 1.3$. Since only one time series is available a scheme for tuning of q_{thres} is left for future studies where many different series are included. The space heating is found simply by subtracting DHW heating from the total heat load

$$\hat{Q}_t^{\text{space}} = Q_t - \hat{Q}_t^{\text{water}} \tag{3}$$

The result of the separation is shown in Figure 2. The uppermost plot shows the original data together with $1.3 \cdot \hat{g}(t)$. The middle plot shows the DHW heating. The lower plot shows the space heating. Therefore, the sum of the two lower plots is equivalent to the uppermost plot. It is seen that the

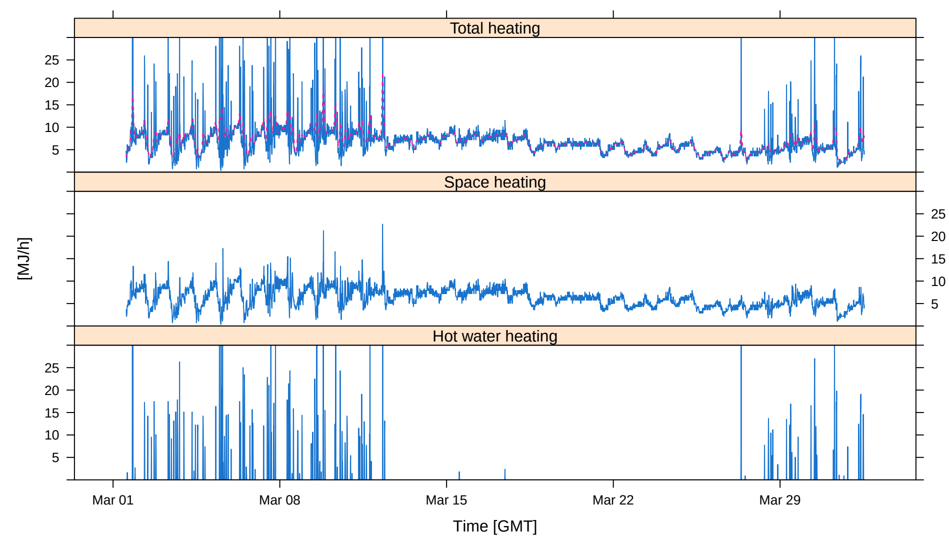

Figure 2: Separating with kernel smoother. The red dashed line is $1.3 \cdot \hat{g}(t)$.

estimated space heating has many short-lived spikes, which is not good. The reason is that the kernel estimate, $\hat{g}(t)$, is too affected by the spikes, which cause that some spikes are below $1.3 \cdot \hat{g}(t)$. The next section is dedicated to show how a modification by using a robust kernel smoother can reduce the influence from the high spikes.

3.2 Robust kernel smoother

The idea behind robust estimation is to make the estimation method robust against outliers or extremes[17]. Optimization methods generally try to minimize some function $\rho(\varepsilon)$ of the residuals ε. In this case the kernel estimator in (1) is a zero order local regression model [6] and can be formulated as

$$\hat{g}(t) = \arg\min_{\theta} \frac{1}{N} \sum_{i=1}^{N} k\left(\tfrac{t-i}{h}\right) (Q_i - \theta)^2 \tag{4}$$

where the residuals minimized are $\varepsilon_i = Q_i - \theta$, hence the least squares method minimizes the sum of the squared residuals $\rho_{LS}(\varepsilon) = \varepsilon^2$. The estimation is made robust by replacing the quadratic function with Tukey's biweight function also known as the bisquare function, see [9]. The biweight estimation minimizes the following function

$$\rho_{\text{biweight}}(\varepsilon) = \begin{cases} \frac{1}{6}\frac{\varepsilon^2\left(\varepsilon^4 - 3\,\varepsilon^2\gamma^2 + 3\,\gamma^4\right)}{\gamma^4} & \text{if } |\varepsilon| \leq \gamma \\ \frac{1}{6}\,\gamma^2 & \text{if } |\varepsilon| > \gamma \end{cases} \tag{5}$$

The biweight function is approximately quadratic for small residuals and constant for residuals larger than γ. A plot of $\rho_{\text{biweight}}(\varepsilon)$ and a scaled version of $\rho_{LS}(\varepsilon)$, together with their derivatives is shown in Figure 3. The derivative is also also known as the influence function. The biweight function

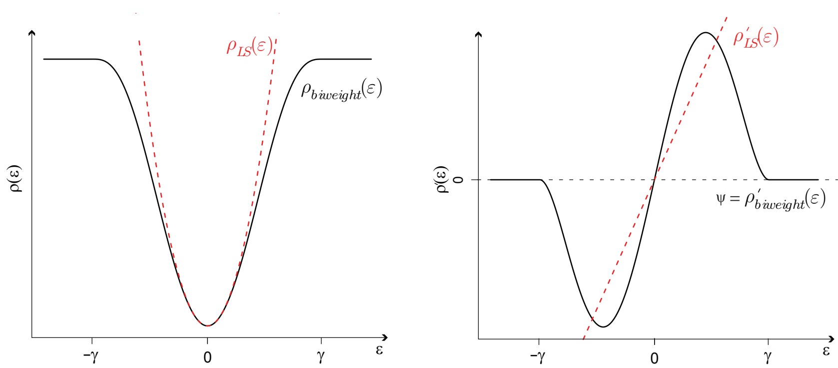

Figure 3: Left: Tukey's biweight and a square function. Right: The derivatives also known as the influence function.

induces that outliers do not cause displacement of the resulting estimate. For residuals further away than the chosen γ threshold the influence function $\rho'(\varepsilon) = 0$, hence the estimate is independent of how much further away the observation is. For the actual heating data a reasonable value was found to be $\gamma = 7$ Mj/h. For a given time t the robust kernel estimate is found by solving the optimization problem

$$\hat{g}(t) = \arg\min_{\theta} \frac{1}{N} \sum_{i=1}^{N} k\left(\tfrac{t-i}{h}\right) \cdot \rho_{\text{biweight}}\left(Q_i - \theta\right) \tag{6}$$

The result of the kernel estimation with a biweight function is shown in Figure 4. It is seen that almost all of the spikes in the space heating are

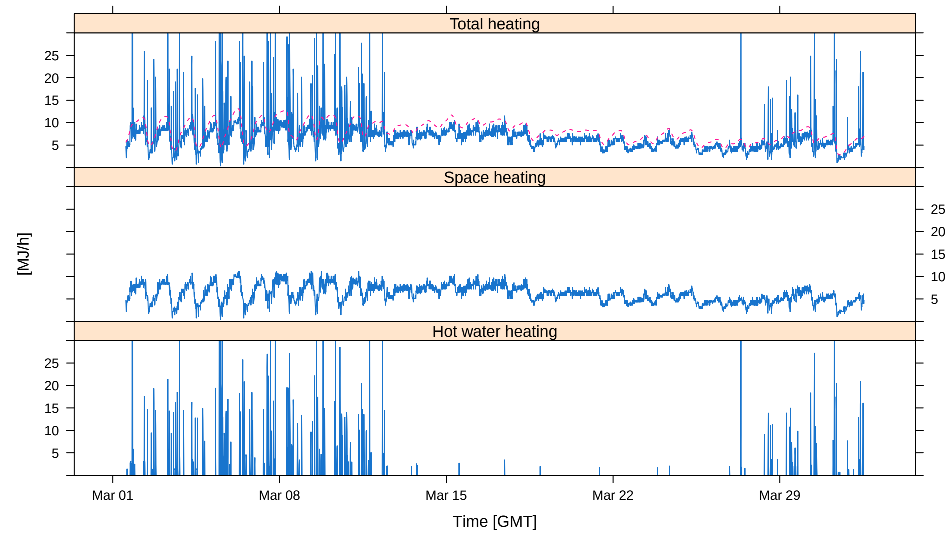

Figure 4: Separating with robust kernel smoother. The red dashed line is $1.3 \cdot \hat{g}(t)$.

removed compared to the ordinary kernel estimate. So using the robust kernel reduces the problem that the kernel estimate was too affected by the large spikes.

4 Discussion

Certainly, it is needed to apply the method on many series with different patterns, and where the DHW and space heating is measured separately, in order to validate the performance more thoroughly. Then also a scheme for automatically tuning the parameters: the kernel bandwidth h, the separation threshold q_{thres} and the γ threshold for the biweight function in the robust estimation scheme, can be developed. Furthermore, for the present heating series a relative value of kernel estimate instead of fixed value as the separation threshold instead was used. However, how this threshold is constructed should be studied in further details.

The use of a robust kernel smoother can be extended in many ways. In the current study a local mean value is estimated this can be extended to robust local polynomial smoothing. Other explanatory variables can also be included, e.g. ambient temperature, solar radiation, and electrical consumption. However, one should not expect to explain all the variation in the data in this way as most houses represent a relative large thermal mass that combined with thermostats creates dynamics in the response. Furthermore, many houses has reduced temperature setpoints during the night which will also give a dynamic response in the total heat consumption.

The proportion of the total heat load that is used for space heating obviously depends on the outdoor climate and therefore on the season. This can be considered as a signal to noise ratio and it would also be of interest to investigate how this approach works for different periods of the year. Another important consideration is the sampling frequency. In this study a sample is recorded every 10 minutes which is on the same time scale as typical DHW usage for dish washing and showering while at the same time being frequent relative to the dynamics of the space heating.

5 Conclusion

A method for splitting the total consumption into DHW and space heating is presented. The method is constructed as a generic method for separating spikes from low frequency variations in time series data. It is assumed that the DHW heating are spikes added to the space heating in the total heat load. First a local average kernel is applied, however the spikes affect the estimates and the results were not acceptable. Therefore a robust estimation is suggested and it is shown that this enables a much better separation of the DHW and space heating. It is found that the method is very promising and that it can be concluded that the method can be used for separating the DHW heating from space heating. However, it is also suggested that a study, where the method is applied on many different heating series and where the DHW and space heating are measured separately, is needed for a more in-depth development and verification of the method.

The described method can be used in other field of operation as well. It is not locked to the application of heating. In any problem, where noisy data include spikes, the described method could possibly provide a technique for removing the spikes.

6 Acknowledgments

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7 References

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Buildings' energy efficiency and RES potential in urban contexts

Main results of the project Cities on Power, www.citiesonpower.eu

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Abstract

The research project Cities on Power, co-financed by the Central Europe program, was focused on the promotion of renewable energy sources (RES) in urban contexts, involving citizens in finding the best solutions to reduce their energy bills. Starting from this objective, the study was extended to the analysis of energy savings solutions for residential buildings. To encourage citizens participation in energy issues, a web-based interactive tool was created. This paper describes a methodology based on an open source GIS tool to estimate the energy consumption, energy saving potential and the use of renewable energy sources in the Metropolitan City of Turin.

The estimation of thermal and electric energy-use for residential buildings

The models used for the energy assessment of existing residential buildings can be divided into the following categories:

- top-down models: energy-use data at urban scale are compared with climate variables, census results and statistical surveys to determine an average energy consumption for existing buildings. These models can compare different variables, but cannot distinguish spatial variations in energy consumption of a Municipality or a territory;
- bottom-up models: these models, at a building scale, are used to evaluate the energy balance of a single building with high detail; together, a set of energy consumption models, can be combined to evaluate the energy consumption of blocks of buildings, districts or cities; for good results at urban scale a large number of data is required. These models can be also used to evaluate energy savings model after building retrofits.

In the project Cities on Power an hybrid approach has been applied with:

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

For this research, the open source tools Quantum GIS (Lisboa version 1.8.0) and GRASS GIS (version 6.4.2) were used. The analysis considers the Metropolitan City of Torino with about fifty Municipalities representing approximately a million and a half of inhabitants, in the North-West part of Italy on a territory of 6,821 km^2.

The data used to define the energy-use models were the following:
Energy-use data: Sustainable Energy Action Plan (SEAP-Covenant of Mayor), considering for example the 2005 as reference year for the city of Torino, and a buildings' survey on energy consumptions of 2,000 typical residential buildings in Turin connected with the district heating network,
Buildings', population and territorial contest data: Technical Map of the Metropolitan City of Torino (CTP), Municipal Technical Map for the City of Torino (CTC), other information as the height of the buildings and the type of roof obtained from Lidar datasets, the 2011 ISTAT census at census section scale, Digital Terrain Model of Piedmont Region (DTM), and
Climate data: outdoor air temperature and the Heating Degree Days (HDD) by climatic ARPA database (http://www.regione.piemonte.it/ambiente/aria/rilev/ariaday/annali/meteorologici).

Considering the spatial distribution of the heated volumes, for residential buildings with different characteristics, the energy-use of the single buildings' models was applied on urban scale. The 2011 ISTAT census data were also used to improve the models considering the average percentage of the heated volume, the type of buildings' envelope, systems' efficiency, period of construction, and the number of inhabitants on census section scale.
Comparing the bottom-up and top-down results, correction factors can be determined to have good results with the overall approach. The simplified models of space heating and hot water production energy-use developed in the bottom-up approach do not take into account important factors such as the spatial variability in: solar gains, indoor/outdoor air temperatures and, mainly, the retrofit of buildings that may have changed their energy consumptions over the years. To consider these variables and to adapt the model to real energy consumption data, the model of the specific energy-use of buildings was multiplied by a correction factor as function of a typical built environment analysed. In Table 1 the data about Turin and other 5 cities in Turin's Province are reported.

In Figure 1 the linear models on energy-use for space heating and hot water production applied to the Municipality of Turin and others cities near Turin (normalized on the average value of the Heating Degree Days of the last 10 years) are represented. The correction factors were used to limit the differences between the model at building and at municipality scale; higher values were founded in the Municipalities with low details GIS database.

More adjustments are necessary to calibrate the models to the real built environment considering that in the municipalities of the Metropolitan City of Torino, the consumption data are much higher than the data recorded by the Sustainable Energy Action Plans. This gap can be explained by an analysis of demographic data, which highlights that the real percentage of heated volume is lower than the one registered by ISTAT census data as the real number of inhabitants are lower than the theoretical one (considering an average value of available gross floor area for inhabitant of 30 m^2 - Regional Piedmont Law 56/1977).

The energy-use models describe correctly the energy consumption of heated buildings but they do not fully understand the spatial variability of the heated and unheated spaces and the real extension of the indoor spaces, especially in mountain areas. Therefore a demographic factor was adopted, taking into account the relationship between theoretical and real population or heated and unheated buildings' spaces. For Torino the demographic factor is 67% and in the Metropolitan City of Torino it varies from 7% to 151%, with higher values on the mountains (with an high percentage of holiday's houses).

Municipality	Volume of buildings (at 2005) Mm^3	HDD (UNI 10349)	HDD (2005)	HDD (last 10 years)	Space heated %	Correction factor
Turin	142.24	2617	2703	2462	0.94	1.04
Ivrea	3.66	2737	3247	2752	0.83	1.05
Strambino	3.37	2720	3174	2850	0.95	1.02
None	2.36	2623	3171	3001	0.95	0.93
Carmagnola	6.96	2717	3299	3076	0.94	1.30
Pianezza	3.07	2735	3220	3043	0.96	1.31

Table 1. Volume of residential buildings, HDD values, percentage of space heated and the correction factor.

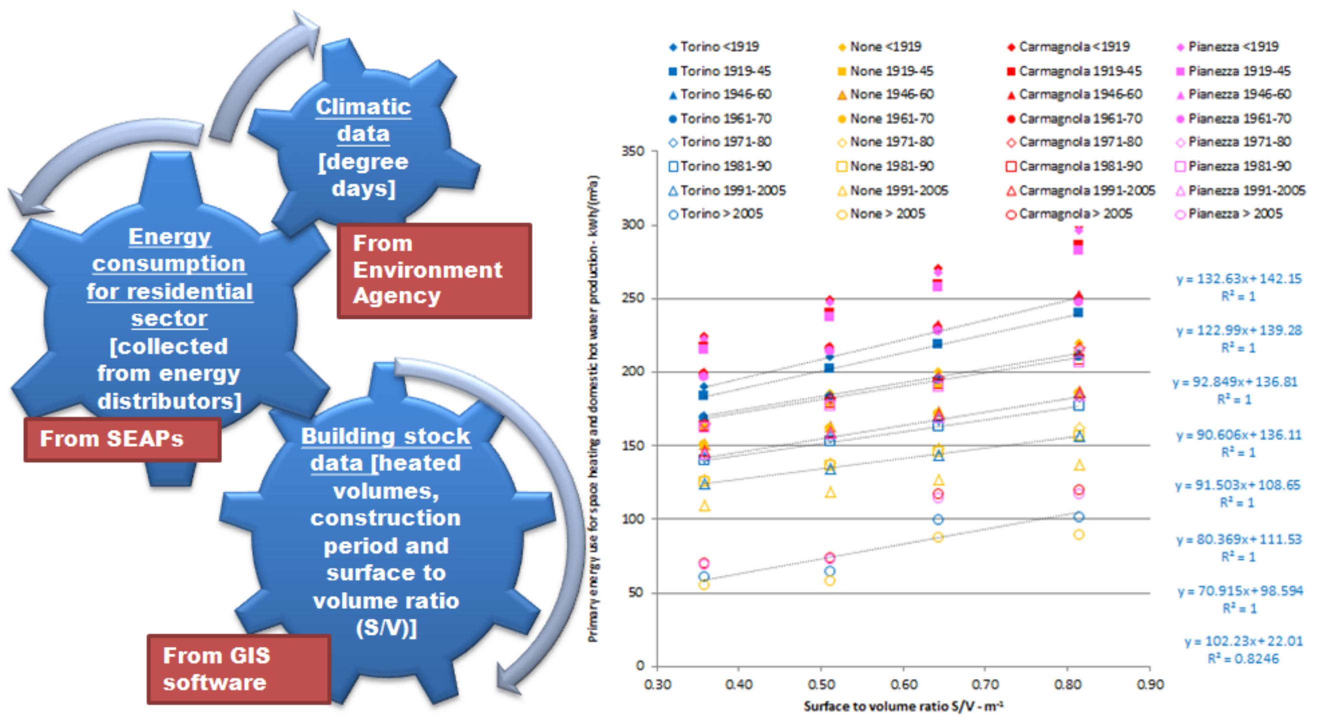

Figure 1. The specific energy-use for space heating and hot water production as function of the building construction period and the surface to volume ratio S/V for residential buildings for cities in the Metropolitan City of Torino: Torino, Strambino, None, Carmagnola and Pianezza (considering an average value of heating degree days of the last 10 years).

For the electricity consumptions in residential buildings, a similar approach has been adopted considering that the electric energy-use depends mainly by the number of inhabitants; using the average percentage of heated space from 2011 ISTAT census and then considering the uninhabited dwellings per building, the number of inhabitants was estimated. On a Municipality scale, the electric consumption in the residential sector for the City of Torino refers to the reference year 2005 and it has been collected from the SEAP: 1,092,488 MWh/year. For the calculation of per capita consumption, the real number of inhabitants in 2005 of 900,748 have been used and the annual per capita consumption is therefore equal to about 1,213 kWh/inhabitant. To validate this value for the electric consumption in the Metropolitan City of Torino, the report “Eighth report on the energy of the Province of Turin” was also used with an average annual consumption of 1,215 kWh/inhabitant. By applying the per capita electric consumption to the number of inhabitants in each municipality and in each building, the relative electrical energy use is calculated.

In Figure 2 and 3 the thermal and electric specific energy-use for each municipalities in the Province of Turin are represented. These results have been obtained from the data at buildings scale. About electric energy-use value in the north-west side of the province, some adjustments have been made considering the high percentage of holiday's houses.

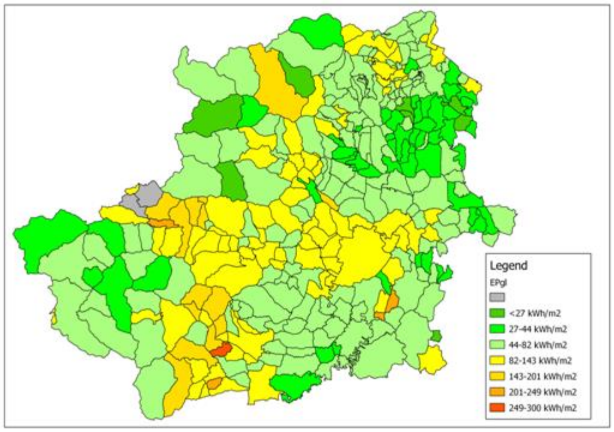

Figure 2. The specific energy-use EP_{gl} [kWh/m^2/y] for space heating and hot water production in residential buildings in the Province of Turin.

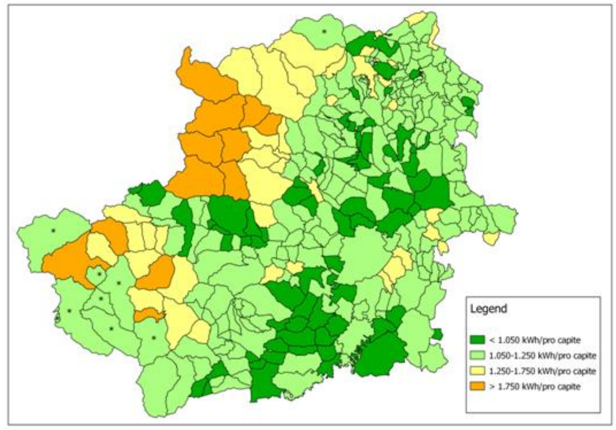

Figure 3. The specific electric energy-use [kWh/inhabitant] for residential buildings in the Province of Turin.

The estimation of energy savings potential

The evaluation of the energy savings potential has been carried out simulating the different sets of renovation actions considering the national (D.M. December 28th 2012) and regional (D.G.R. 4/08/2009, n. 46-11968) regulative framework. Starting from the energy-use data of residential buildings, it is crucial to understand the feasibility of buildings' retrofit interventions for energy savings in a low, medium and long terms. To evaluate the retrofit feasibility, the following socio-economic variables of 2011 ISTAT census have been used, as the energy savings rate depends on the type of building but also on the interest and possibility of citizens to invest in renovation:

1. The age factor (f_a): the ratio between population with an age in the range of 25 - 69 years and the total population.
2. The employment factor (f_e): the ratio between the employed part of population and the total active population.
3. The property factor (f_p): the ratio between the number of families that own their apartment and the total number of families.
4. The family factor (f_f): the ratio between the number of families composed by 1-2 components and the total number of families.
5. The education factor (f_{ed}): the ratio between the population with high school diploma or higher instruction level and the total population.
6. The building's occupation factor (f_o): the percentage of buildings that are occupied during the whole year.
7. The period of construction (f_{pc}): the number of buildings built before 1945 over the total number of buildings.

Each of the analyzed factors represents some aspects of the socio-economic condition of the community, influencing the feasibility of buildings' renovation interventions. Each factor has a specific weight, depending on how much its influence is strong; bigger is a factor, higher is the feasibility of renovation interventions on residential buildings.
To calculate the global feasibility index F for each census section of the Metropolitan City of Torino a multiple linear regression model can be apply, normalizing all the socio-economic factors to a medium value of 0.5:
$F = \alpha_1 \,.\, f_{a,n} + \alpha_2 \cdot f_{e,n} + \alpha_3 \cdot f_{\mathrm{p,n}} + \alpha_4 \cdot f_{f,n} + \alpha_5 \cdot f_{ed,n} + \alpha_6 \cdot f_{o,n} + \alpha_5 \cdot f_{pc,n}.$

Considering the global feasibility index as the number of energy performance certificates APE due to retrofit interventions for building, the following multiple linear regression models have been founded:
$F_{APE/b} = 0.421 \cdot f_{pc,n} + 0.137 \cdot f_{ed,n} + 0.078 \cdot f_{e,n} + 0.024 \cdot f_{o,n}.$

It seems that the more influencing variables are: the buildings' period of construction, the education level, the employment rate and the occupied percentage of the buildings.
Applying different levels of renovation to the buildings as indicated in Table 2, different results in energy savings can be reached. The four classes were defined from the average value of feasibility index F (0.5) ± its standard deviation (0.08).

	First class	Second class	Third class	Fourth class
Feasibility index	<0.42	0.42 - 0.50	0.50 - 0.58	> 0.58
Number of buildings in the Metropolitan City of Torino	13%	42%	39%	6%
Number of buildings in Torino	20%	54%	23%	3%
Renovation level	windows substitution	+ boiler substitution	+ thermal insulation of slab and roof	+ thermal insulation of facades

Table 2. The number of buildings for each renovation feasibility class and level of renovation.

Some results in energy savings are reported Figure 4 and 5 considering a short-long term perspective.

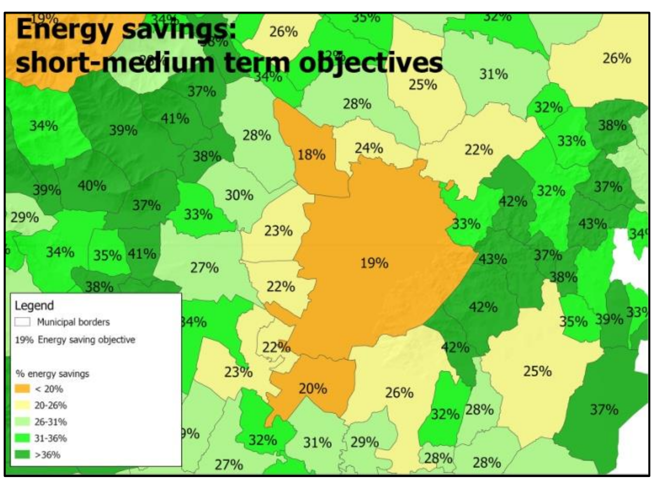

Figure 4. Energy saving potential improving energy efficiency in residential buildings' at short-medium term

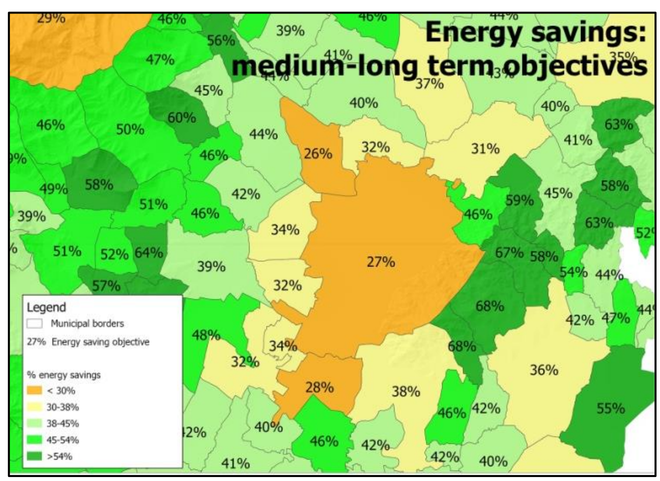

Figure 6. Energy saving potential improving energy efficiency in residential buildings' at medium-long term

In Turin the energy saving potential is quite low (from 19 to 27%) but in the South-East municipalities can reach 42-68%. Different objectives can be reached in energy savings for the various municipalities.

The estimation of RES potential with solar roof integrated technologies

The objective of this analysis was to use the current solar irradiation models to calculate the incident solar irradiation, taking into account the shadowing effects caused by the terrain model and the buildings, but also the exposure, the slope and the available area of the rooftops.

The Geographical Information Systems (GIS) were used to represent data, but also to produce new information, enabling the public administrations to evaluate their energy policies and providing to the citizens a powerful instrument to obtain a preliminary indication of the feasibility and the potential energy production of a solar plant on the roof of their building.

The procedure used in this analysis can be synthesized in:

- defining the digital surface model (DSM) of the built environment to evaluate the obstructions and the rooftops on which the solar technologies could be installed,
- evaluating the incident solar irradiation and,
- calculating the potential energy production for each building and then for each Municipality with solar technologies integrated in the rooftop of existing buildings'.

The potential of rooftop integrated solar energy sources was analyzed taking into account the urban context and the thermal and electric energy-uses. In Figure 6, the results for the Metropolitan City of Torino are represented. Only the 10% of the solar energy captured by the rooftops can be directly used by the citizen to produce thermal and electric energy; this result is typical for high density urban areas and varies from 5 to 23%, influenced principally by the buildings' roofs' orientation and type and by the shadowing effects.

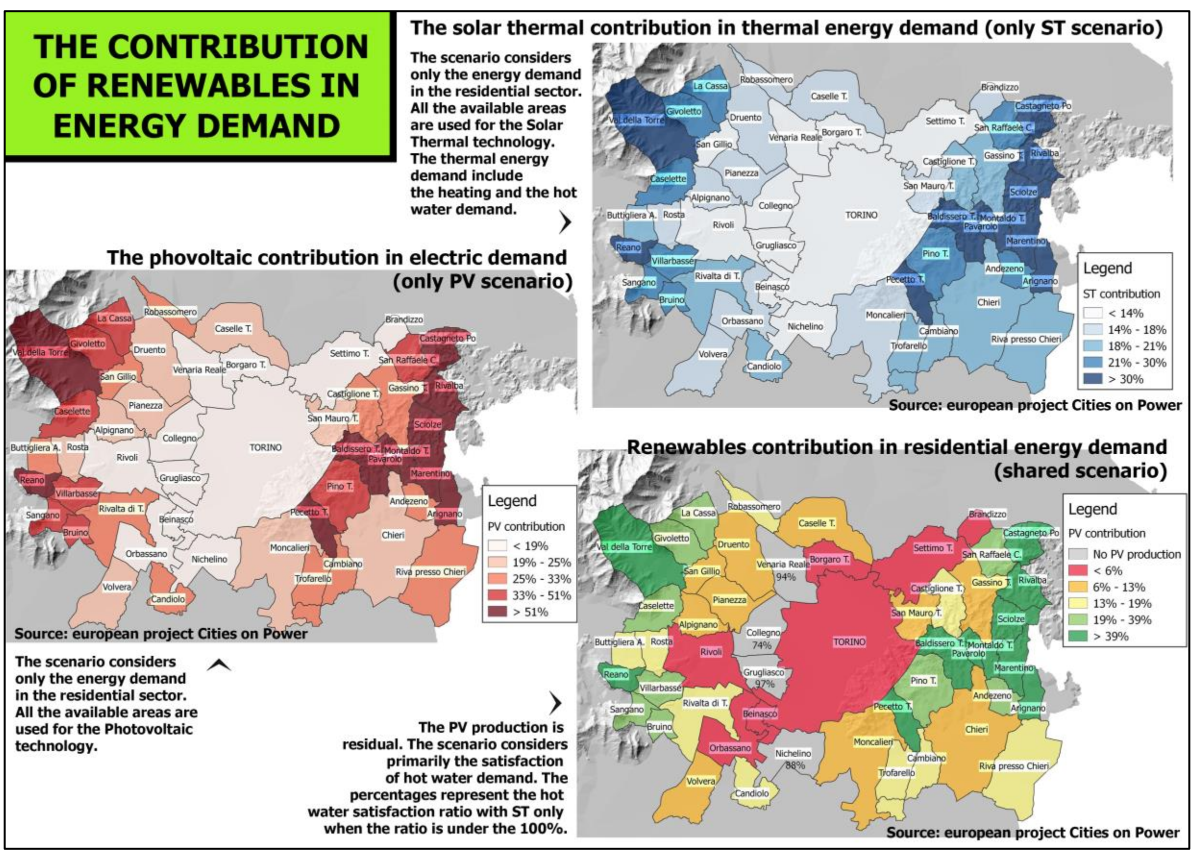

Figure 6 - The contribution of solar renewables in energy-use in the residential sector.

Conclusions

The energy saving potential and the renewable solar energy sources are differently distributed on the territory and the energy policies should consider this feature to improve their effects. Every Municipality can then establish different objectives in term of buildings' energy savings and renewable energy production.

More results of the project Cities on Power Project can be found in:

- "Analisi del fabbisogno di energia termica degli edifici con software geografico libero. Il caso studio di Torino", G. Mutani, G. Vicentini, Journal: LA TERMOTECNICA, vol. 6, July-August 2013, pp. 63-67, ISSN: 0040-3725 (http://www.latermotecnica.net/pdf_riv/201307/20130715004_1.pdf).
- "L'applicazione delle tecnologie fotovoltaiche integrate sulle coperture degli edifici con software GIS", S. Bonesso, G. Mutani, T. Hubina, A. Ramassotto, Journal: GEOmedia, vol.17, n.2, 2013, pp.6-11, ISSN 1128-8132 (http://www.mediageo.it/ojs/index.php/GEOmedia/article/view/268).
- "Gli open data per l'analisi del fabbisogno di energia primaria degli edifici residenziali e del potenziale risparmio energetico", G. Mutani, G. Vicentini, Smart City Exhibition, Bologna, October 16-18th 2013, Ed. Forumpa, pp. 15-37, ISBN 9788897169260.
- "Evaluating the potential of roof-integrated photovoltaic technologies using an open geographic information system - La potenzialità dei sistemi solari fotovoltaici integrati nelle coperture degli edifici con le tecniche GIS open source", G. Mutani, G. Vicentini, 8th ENERGY FORUM on Advanced Building Skins, EF ECONOMIC FORUM, November 5-6th, 2013, Bressanone (BZ), pp.87-92, ISBN 978-3-9812053-6-7 (http://www.energy-forum.com/fileadmin/content-2013.pdf).
- "La fattibilità degli interventi di riqualificazione energetica per gli edifici residenziali. L'applicazione ed i risultati di un'analisi socio-economica nella Provincia di Torino", G. Mutani, G. Vicentini, Journal: IL PROGETTO SOSTENIBILE, December 2013, Edicom Ed., pp. 80-87, ISSN: 1974-3327 (http://www.ilprogettosostenibile.it/custom/sez_magazine.php?browse_id=1996).
- "Un modello per valutare il consumo energetico per la climatizzazione invernale degli edifici residenziali. Il caso studio di Torino. A model to evaluate the heating energy consumption for residential buildings in Turin", G. Mutani, M. Pairona, Journal: L'Ufficio Tecnico, Ed. Maggioli, Italy, May 2014, pp.21-36, ISSN 0394-8293 (http://www.preview.periodicimaggioli.it/browse.do?nr=2014_5&id=11).
- "Il consumo energetico per la climatizzazione invernale degli edifici residenziali. Un modello per Torino, A model to evaluate the heating energy-use for residential buildings in Turin", G. Mutani, Journal: NEO EUBIOS, vol. 50, December 2014, pp. 16-23, ISSN: 1825-5515 (http://www.anit.it/neo-eubios-rivista).
- "Building energy assessment and urban form", C. Delmastro, G. Mutani, L. Schranz, G. Vicentini, IX National Congress AIGE - Associazione Italiana Gestione dell'Energia, Catania, 17-18 Settembre 2015, ISBN: 978-88-940975-0-4.
- "Urban morphology and energy consumption in Italian residential buildings", C. Delmastro, G. Mutani, M. Pastorelli, G. Vicentini, International Conference on Renewable Energy Research and Applications ICRERA-2015, Palermo, 22-25 November 2015, in press.
- "Buildings' energy consumption, energy savings and the availability of renewable energy sources in urban contexts: the potential of GIS tools", G. Mutani, G. Vicentini, Journal of Civil Engineering and Architecture Research, Volume 2, Number 11, November 2015, ISSN: 2333-9128, in press.
- "The role of urban form and socio-economic variables for estimating the building energy savings potential at the urban scale", C. Delmastro, G. Mutani, L. Schranz, G. Vicentini, International Journal of Heat and Technology, in press.
- Solar web portal: http://energia.sistemapiemonte.it/ittb-torino.

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