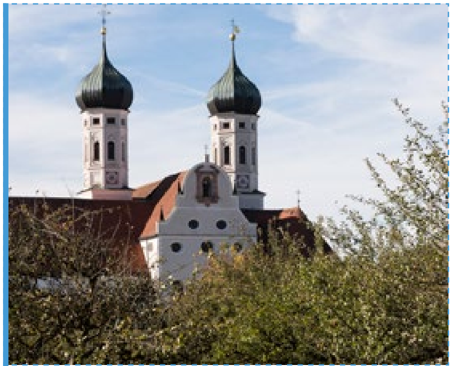
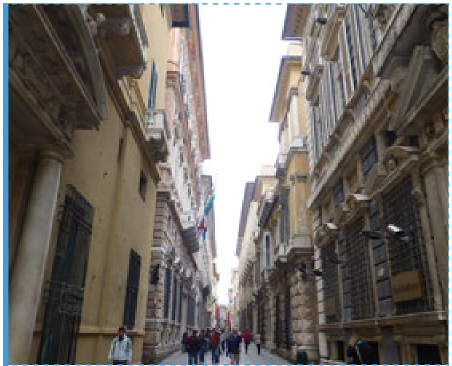
The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

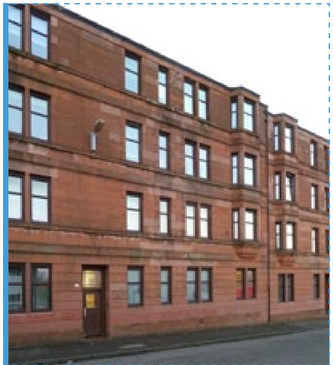
ENERGY EFFICIENCY IN EUROPEAN HISTORIC URBAN DISTRICTS

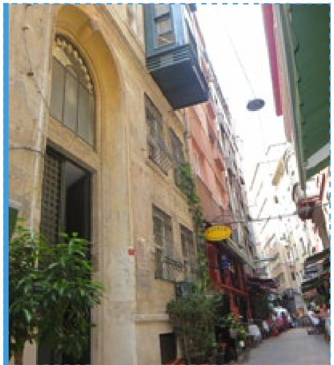
A PRACTICAL GUIDANCE


Benediktbeuern Germany


Budapest Hungary


Genoa Italy


Glasgow UK


Istanbul Turkey


Santiago de Compostela Spain


Visby Sweden

TABLE OF CONTENTS

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

EDITORIAL

Isabel Rodriguez-Maribona
Tecnalia Research & Innovation
Project Coordinator

Gunnar Grün
Fraunhofer Institute for Building Physics IBP
Scientific Coordinator

We are pleased to present you the booklet **Energy Efficiency in European historic urban districts – A practical guidance**. It provides insights into the main results and findings of the four year European funded EFFESUS project. Organised in five main chapters, the booklet contains a wide range of information to support communities in improving energy efficiency in European historic districts. It includes key project outcomes of EFFESUS such as strategies for energy assessment, the analysis of existing solutions, the development of innovative solutions and a software-based Decision Support System, as well as presenting non-technical barriers encountered and experiences of the case studies.

EFFESUS gave us, the 23 partners from 13 countries, the possibility to cooperate and expand our knowledge and we are now delighted to share our experience. We hope you will enjoy reading this publication and will find it interesting. We encourage other professionals to take advantage of our results to build more sustainable historic districts and to foster mutual exchanges.

More information on the project's outputs can be found on the website http://www.effesus.eu/about-effesus/project-results/deliverables

INTRODUCTION

INTRODUCTION

Buildings have a significant impact on energy use and the environment. Across the European Union, they are responsible for approximately 40% of the energy consumption and 36% of CO_2 emissions. The majority of buildings in Europe are located in cities, which accommodate around 73% of the population, a share which is expected to increase to over 80% by 2050 [1]. Growth in population, increasing demand for building services and high comfort levels assure that the upward trend in energy demand will continue in the future.

EFFESUS has adopted an inclusive definition of historic urban district: 'a significant grouping of old buildings, built before 1945 and representative of the period of their construction or history, and comprising buildings which are not necessarily protected by heritage legislation'. The European building stock built before 1945 represents 23% of the total [2], and even if a reduced number of these buildings are officially listed, a substantial proportion possesses heritage significance [3].

The European Union has developed several programmes, guidelines and directives on energy efficiency in buildings in order to harmonise instruments and criteria, such as the recast of the Energy Performance of Buildings Directive 2010/31/EU (EPBD), which strengthen energy performance requirements; or the European Recovery Plan which considers energy efficiency as one of the actions to be tackled to overcome the current crisis.

Most of the existing developments in energy efficiency address new constructions without dealing with the uniqueness of historic structures. New solutions typically address individual buildings without considering the urban dimension, where interconnections between buildings and other infrastructures enable different solutions.

EFFESUS has been devised in order to reduce the environmental impact of Europe's valuable urban heritage, by making significant improvements to its energy efficiency while preserving its cultural and historical values. The project brings together the expertise of 23 partners from 13 countries, 12 of them being small and medium enterprises. It develops and demonstrates, through case studies, a methodology for selecting and prioritising energy efficiency interventions based on existing as well as newly-developed cost-effective technologies and systems compatible with heritage values. This methodology is implemented in a Decision Support System, a set of tools and information models to facilitate an evidence-based diagnosis and decision-making.

References:

[1] United Nations. Department of Economic and Social Affairs, World Urbanization Prospects, 2014 revision. ISBN 978-92-1-151517-6

[2] K. Dol, M. Haffner (2010). Housing Statistics in the European Union 2010. Ministry of the Interior and Kingdom Relations, The Hague, The Netherlands

[3] P. Eriksson, C. Hermann, S. Hrabovszky-Horváth, D. Rodwell (2014). EFFESUS Methodology for Assessing the Impacts of Energy-Related Retrofit Measures on Heritage Significance. The Historic Environment, Vol.5 No. 2, July 2014, 132-49

1 STRATEGIES FOR ENERGY ASSESSMENT OF HISTORIC URBAN DISTRICTS

1. STRATEGIES FOR ENERGY ASSESSMENT OF HISTORIC URBAN DISTRICTS

District scale is the operational scale to deal with the implementation of energy improvements and their subsequent management as the major potential is reached by the efficient use of resources [1]. In order to optimise energy consumption and reduce CO_2 emissions, strategies should be addressed at district scale, although the executive scale should be connected with the building and building component scales.
Historic cities can become a model of urban efficiency through the development of new strategies and analysis of existing information if the district and building scales are properly addressed and interconnected.
The selection of actions suitable for each district depends upon the specific characteristics and restrictions of the historic district considered, along with the properties and limitations of the solutions proposed and the criteria that these actions will serve. Historic districts, as urban ecosystems, generate a large volume of heterogeneous information (at different scales, for a different use, of a different nature, from different tools and formats and from different stakeholders´ origin). The informational complexity of historic cities (due to their spatial, social and cultural richness, but also as result of their vulnerability) make them special beneficiaries of information management strategies. Since the energy management is an inter-scalar topic [2], strategies have to be multi-scalar. This is particularly relevant for historic environments, as it enables the identification of applicable strategies in protected buildings and landscapes.
EFFESUS has addressed this challenge through a historic district categorisation methodology that enables the selection of building groups and representative buildings within the districts and a multiscale data model that structures all the necessary information for the decision-making process. Both will be introduced in detail in the following contributions.

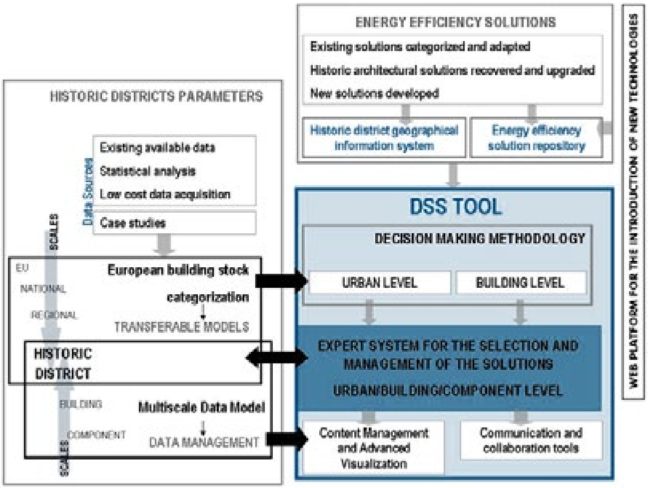


Figure 1: The role of the strategies for energy assessment of historic urban districts in the EFFESUS overall concept are shown in the lefthand part of the figure.

References:

[1] A. Koch. Energy balance of urban quarters for the development of energy efficiency and Management strategies, 2002

[2] G. Barbano and A. Egusquiza, "Interconnection between scales for friendly and affordable sustainable urban districts retrofitting," in 6th International Building Physics Conference, IBPC 2015, 2015.

1.1 HISTORIC DISTRICT CATEGORISATION METHODOLOGY

As the EFFESUS project focuses on districts rather than individual buildings we must take the district as a whole into account by identifying the interaction between buildings, the potential for common solutions and synergies. The district model needs a scale that is larger than the individual building scale to account for interactions between buildings. For modelling the district as a whole one needs to take into account the following aspects: laws and regulations, climate, land use, shading effects and energy supply.

Building stock modelling is a tool for the planning and development of policies. For practical reasons, the investigation of a historic district as a whole cannot be made on a house by house basis. The building stock must somehow be reduced to a manageable number of categories that provide a satisfactory statistical representation of the whole stock.

Method for district modelling and categorisation

The buildings selected to represent the whole building stock can either be sample buildings or archetype buildings. Sample buildings are actual buildings in a specific district. Archetype buildings are theoretically constructed buildings based on statistical data and field surveys. The archetype building can be constructed to better represent a segment of buildings within a building stock than would be possible by using only sample buildings.

The definition of the data structure (the required information) and the categorisation (the processing of information) must go hand in hand. The categorisation method will define the need for data just as the availability and structure of data will set the limits for the categorisation. In order to draw conclusions about energy saving on a district level for example, the results from the analysis of the typical buildings have to be extrapolated.

The scale of the district and the building stock will determine the method for data collection and modelling. On a national or European scale, statistical methods have to be used. On single well-defined districts, both data collection and categorisation can be more precise and can be adapted to local conditions.

In the following, a method to model the buildings in a district will be described. It is based on a categorisation where the building stock is represented by a limited number of typical buildings. The selection of typical buildings is an intricate balance between the availability of data, accuracy, and the work needed to analyse the selected building types. In most cases we will need an iteration to find the right balance. The flowchart below (Figure 2) shows the overall process. In the following text this method will be described step by step.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

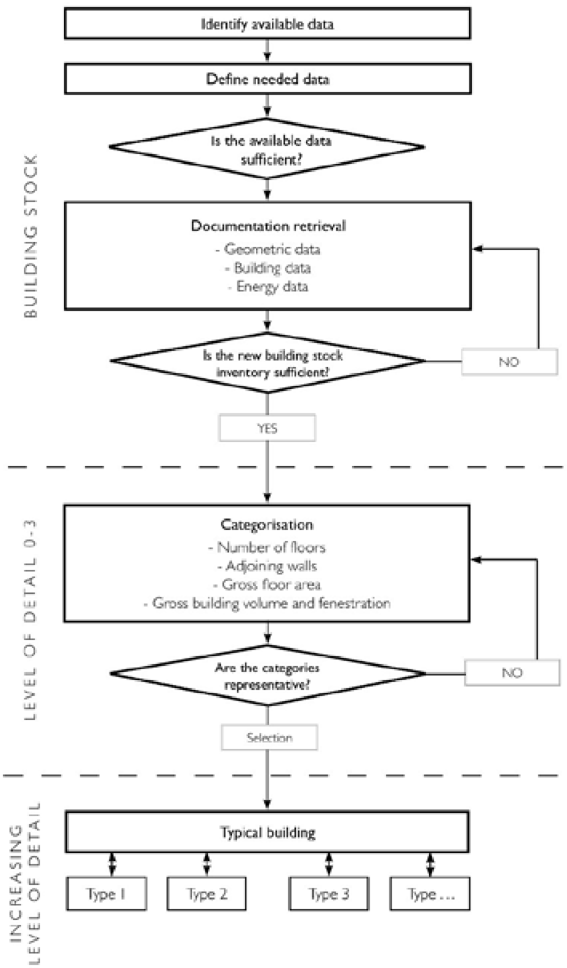


Figure 2: The flowchart of the iterative process of the categorisation method.

Identify available data

The identification of available data should preferably be carried out in a joint effort with local, regional and/or national authorities. This stage should aim to answer the following questions:

- What kind of data was collected in previous surveys and studies?
- Was the data adequate and reliable?
- Which were the general conclusions and results?
- Did the surveys present the results in any new platforms or projects?
- Are any of these accessible today? If so, in which format?

Define needed data

The minimum requirement of data is:

- Building identification
- Year of main construction
- Building geometry
- Number of adjoining walls
- Exterior envelope
- Type of construction (from pre-defined list)
- Operation/use
- Predominant energy supply and distributing system

Assessment of collected data

Once the data collection process is done, it is necessary to assess if there are sufficient data or not. If not, one should gather supplementary data to the extent that is necessary. This step will be repeated again once the typical buildings have been generated and if they turn out to be inaccurate or too numerous, for example.

Categorisation

The collected data provide input to a tree structure that is used to identify the typical buildings of a building stock or districts (see Figure 3).

The result is a limited number of physical categories that represent the district. Each physical category can be divided into subcategories with increasing levels of details.

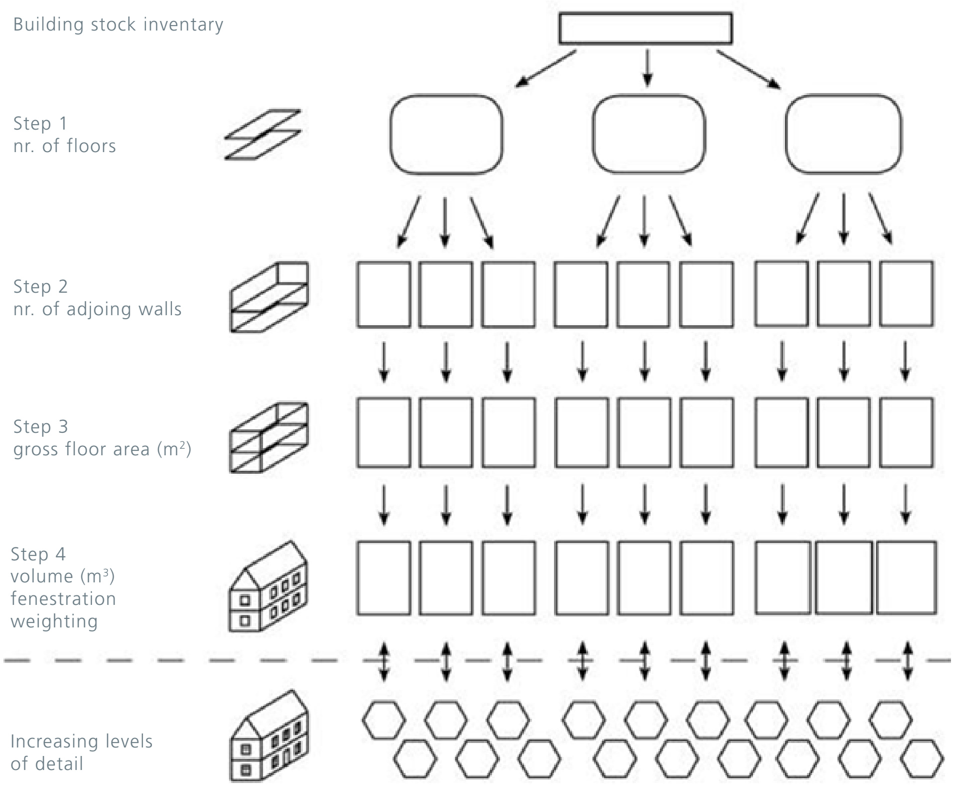


Figure 3: The tree structure shows the flow of the actual categorisation method.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

The process of categorising a building stock is divided into five steps, as described in the following:

Step 1

The primary step addresses the issue of clustering the total amount of buildings according to the number of stories each building has. For example:

- One storey
- Two stories
- Three stories or more

Note that the attic space is irrelevant at this point. Therefore, a one storey building with a converted loft is considered to be only one storey. Since multi-storey buildings generally account for more area and volume of the total mass, one can increase the numbers of clusters as needed. We must however keep the variables at a minimum. If not, the number of categories will grow to the point where this approach is not useful anymore.

Step 2

Secondly, the categories are divided into the number of adjoining walls to other buildings. This means:

- Detached building (0)
- Semi-detached building (1), or
- Two or more adjoining boundaries (≥2).

Step 3

The third step is a calculation of the median value of the gross floor area (GFA) based on the buildings external dimensions.

Step 4

Now we have information on adjoining walls and gross floor area on a specific number of categories. In order to build a 3D-model deriving from these values, we proceed to define these three variables in the following order:

1. The median value of roof-shape and the possible existence of converted loft.
2. The median value of the gross building volume in (m^3).
3. The typical window area (transparent surfaces) in (m^2).

This results in a number of physical categories describing the building envelope and the geometry. The weighted percentage (by number of buildings or building volume) indicates how common each category is. If a percentage is very low (less than 5%) the associated category can be excluded in order to get a manageable number of categories.

Increasing levels of detail

Based on the main physical categories of the building stock, subcategories can be used to reflect increasing levels of detail taken into account. There are only practical limitations to how many categories can be added at this level. Some subcategories are described below.

Construction

This variable includes information on the main building technique and material, e.g. different masonry or timber constructions along with their typical thermal characteristics (U-values).

Heating systems

This includes heat source, distribution system (within the building) and control system.

Types of windows

Whereas the typical geometry of windows is defined in step 4 of the categorisation method, the types of windows and glazing will vary.

Impact indicators

For the purpose of the given scale in building stock categorisation the most relevant impact indicators are:

- Building and urban fabric compatibility,
- Historical values and conservation principles.

Once we have assessed which are the most representative increasing levels of detail, we can identify them as typical buildings, choosing an appropriate amount of objects.

Visby case study

Visby World Heritage City has been used as a case study for developing the method of categorisation of building stocks within the EFFESUS project. A major inventory of the building stock of Visby was conducted during 2013. Visby is a medieval Hanseatic city surrounded by a city wall and situated on the west coast of the island Gotland. The city was declared a World Heritage Site in 1995 because of:

"Its outstanding universal value, representing a unique example of a north European mediaeval walled town which preserves with remarkable completeness a townscape and assemblage of high quality ancient buildings"

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

The identification and collection of information was done in three main fields:

- General building data
- Geometrical building data
- Energy data

Based on the inventory, the historic district of Visby consists of:

- 1,235 buildings with an average of 0.6 secondary buildings
- Buildings built before 1945 account for 83% in the historic district
- The number of listed buildings is 314.

Applying the categorisation method on the building stock of Visby results in eight categories of typical buildings. These typical buildings represent 94% of all buildings that can be modelled for energy assessment, adding increasing level of detail for example heating system, heritage values, construction type etc.

Conclusions

A structured organisation and categorisation method for historic districts has been devised based on the state of art of existing district modelling and categorisation, with two new aspects added. The first aspect is that the method developed within the EFFESUS project allows for a flexibility which helps the categorisation given the amount of data available for the specific district. The second aspect is that the method includes an impact indicator that accounts for heritage values in relation to energy interventions.

The method has been shown to be applicable for the historic building stock of Visby, where the result of the categorisation method gave a manageable number of building categories representing the majority of the total building stock. It is also compatible with the City GML data model. The web-based categorisation tool has been developed with the presented method as a base, and it has been further used in the case study for the historic district Santiago de Compostela in Spain.

1.2 MULTISCALE DATA MODEL

A strategy for information management for the sustainable renovation of historic district requires the definition of a common urban multiscale information model:

- Generic
- Interoperable with other data models and tools for management analysis as well as for decision-making, and
- Containing semantic and geometric information.

In the EFFESUS project, this challenge is tackled with a multiscale information model based on CityGML, a standard data model [1]. This model structures all the information of the district that is necessary for decision-making and management (geometric and semantic information) into a single interoperable data model that integrates information from different fields and at different levels of detail. The model is based on international standards in order to make it interoperable with other data models and other tools (analysis tools, management tools, decision-making tools, etc.) and allow connection between Building Information Models (BIM) and Geographic Information System (GIS) models.

The multi-scalarity is one of the key properties of CityGML, since it supports different levels of detail. These levels are necessary to reflect the data collection of independent processes with different application requirements and facilitate the visualisation and analysis of data.
The multiscale information model has been implemented for the cities of Santiago de Compostela in Spain and Visby in Sweden. The data model has been constructed based on a methodology for semi-automatically build 3D-models using public domain data (cadaster, LIDAR data, available 3D-models, etc.). The CityGML standard is intended to be a universal model independent of the application domain. CityGML defines the most general types of objects and attributes that are included in the applications at urban scale. However, in order to fulfil the requirements of the EFFESUS project, it is necessary to define new elements or add attributes to the existing ones. For this purpose, CityGML defines the Application Domain Extension (ADE). Within the EFFESUS project, four specific extensions have been developed:

- Cultural Heritage domain extension
- Energy Performance domain extension
- Indicators extension, and
- Dynamic extension.

The Cultural Heritage domain extension contains information on the cultural significance of historic districts, so that its retention can be ensured in the development of renovation strategies. The extension identifies character-defining elements, compatibility limits and requirements of heritage legislation. This data will be used as constraints in the decision-making process. If the data are sufficiently complete, this model extension will enable the Decision Support System developed in EFFESUS (see chapter 4 of this booklet) to disregard any retrofit measure which would cause damage to a district's cultural significance.

The Energy Performance domain extension collates information at district, building and building component level, relating to the energy performance of a historic district. This allows estimating the energy performance of the buildings and the district.

The Indicators extension represents a picture at a specific time. A picture may represent the real status or a simulated one. The indicator will store information about the situation before any intervention takes place and after one or several interventions, in order to monitor the results of the renovation strategy. The indicator extension includes indicators identified divided into four categories:

- Environmental conditions
- Embodied energy
- Operational energy, and
- Economic return

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

There is basic information that is constantly changing due to the influence of the building conditions, climate, season and use. The feature of representing temporal information to track changes, updates or interventions over time has been identified as a requirement of the EFFESUS data model. This dynamic extension includes all the data required for monitoring information, which changes frequently over time and is relevant for the assessment of the interventions carried out. Dynamic ADE includes information regarding indoor conditions and energy use, and for each of the parameters identified is stored the time and value of the measure.

References:

[1] G. Gröger, T. H. Kolbe, C. Nagel, and K.-H. Häfele, OpenGIS City Geography Markup Language (CityGML) Encoding Standard, Version 2.0.0. Open Geospatial Consortium, 2012.

2 ENERGY EFFICIENCY SOLUTIONS FOR HISTORIC BUILDINGS AND DISTRICTS

2. ENERGY EFFICIENCY SOLUTIONS FOR HISTORIC BUILDINGS AND DISTRICTS

EFFESUS has researched and developed appropriate solutions for retrofitting historic buildings in European urban districts. The long-term objective is to achieve carbon neutral buildings and districts, for which it is necessary both to reduce the demand for energy and to maximize the amount of renewable energy supplied. Buildings which cannot be retrofitted due to their architectural and historical features will need more renewable energy to achieve carbon neutrality. This is possible with efficient district renewable energy systems, examples of which are available in the EFFESUS repository.

EFFESUS has developed a state of the art repository of energy efficiency measures and renewable energy technologies which are tried, tested and commercially available. This repository is combined with innovative software tools which can produce 3D mapping of urban districts and a Decision Support System to enable the analysis and development of effective retrofit strategies.

Solutions must be appropriate for both the local climate and the heritage values of specific districts. The original design and construction of historic buildings limits the amount and type of energy efficiency retrofitting that can be achieved. However, modern services in these buildings can be made more energy efficient without impacting the heritage value with advanced sensors, controls and management systems. Upgrading the control systems to reduce the use of energy and ensure comfortable conditions is very cost effective. One of the most cost effective retrofitting strategies is retro-commissioning all the services so that they operate optimally. Changing people's behaviour in the buildings can also be a no-cost measure, providing significant energy savings as well as improved comfort conditions for occupants and users. The Budapest case study uses a number of control strategies combined with innovative lighting and ventilation systems.

Integrating renewable energy into a historic urban district may at first seem impossible due to the significant visual impact of many well-known technologies. However, for example, if renewable electricity can be made available from the local grid to power small scale heat pump systems hidden from view in roofs and basements, then power, heating, cooling and hot water can be generated very efficiently and cost effectively. Alternatively, if bio-gas is produced locally from biomass waste, then the renewable bio-gas can be piped in a small bore network integrated into the streets during paving maintenance programmes.

There are many creative solutions for historic buildings and urban districts which EFFESUS has identified, categorised, characterised and made available in the technical repositories.

2.1 TECHNICAL REPOSITORIES

The EFFESUS repository is a web platform available at http://www.dappolonia-innovation.com/Effesus5/. At this link, any user can register in order to be allowed to navigate into the repository.
Once registered and authenticated, the user can have access to the index page of the repository, which contains the links to five thematic sections and related data.
The five sections that constitute the repository's contents, indicated also in Figure 4, are:

1. Existing technologies for the retrofitting of historic buildings
2. Existing technologies supplying renewable energy within historic districts
3. Climate analysis - Passive retrofitting solutions
4. Best Practices
5. Indicator List

In the following paragraphs, each section in the repository – which can be visualised and consulted by a registered user – is described.

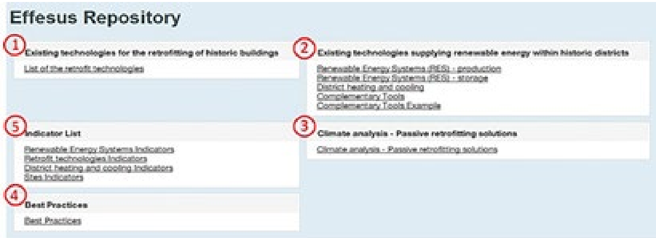


Figure 4: EFFESUS repository index page

Existing technologies for the retrofitting of historic buildings

In this section of the repository, technologies, systems and tools in use or near application for the energy retrofitting of historic buildings are listed, described and categorised. For the categorisation of retrofitting solutions, the approach of a professional user towards a building retrofit has been chosen, going step by step through the individual retrofit issues listed below.

A. Baseline Assessment
B. Energy management
C. Air tightness
D. Ventilation
E. Daylight and solar loads
F. Solar reflectance of external materials
G. Thermal performance of external envelope
H. Thermal mass of building
I. HVAC enhancement and commissioning
J. Electrical equipment
K. Water usage
L. Energy storage
M. Handover & evaluation

For each retrofitting solution, a registered user can access the following information:

- Retrofit Step & Issue: Number of retrofit step & descriptive title of the retrofit issue
- Potential Retrofit Measure: Descriptive title of the retrofit measure
- Metric
- A short commentary of the retrofitting solution
- WHAT: Technical characterisation of the measure
- WHY: List and/or description of the main advantages and list and/or description of the possible drawbacks to be considered
- WHEN: Under which conditions does the proposed solution work well

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

- WHERE: Here conservation aspects are considered by specifying if the solution is typically compatible with heritage conservation standards and on which heritage values it might have an impact
- ENERGY SAVING POTENTIAL: Qualitative characterisation of the energy saving potential as a "first guess" – low, medium, or high
- Key parameters for calculation: Parameter that is mostly important for the actual energy performance calculation
- Example for saving potential
- TOOLS: Related design, monitoring, measurement and information tools
- COST: Economic characterisation of the measure in terms of relative cost – low, medium, or high
- References where the information has been extracted from
- Space for related best practice examples.

For each retrofitting measure, it is also indicated on which element of a building such measure can have an impact or if the retrofitting measure influences the energy performance of the overall building (Overall building, Windows, Ceilings, Internal walls, External walls, Roofs, Shading devices, Installations, etc.). Finally, each retrofitting solution is linked to the related indicators and a registered user can evaluate the assigned values against the indicators.

Existing technologies supplying renewable energy within historic districts

Within this section, a registered user can consult the information regarding Renewable Energy Systems (RES) (1), Energy distribution systems (2), Energy storage devices (3) and Complementary tools (4), structured as described in the following paragraphs. Each of these technologies is linked to the related indicators and a registered user can evaluate the assigned values against the indicators.

1) Renewable Energy Systems (RES) - Production

In this section, for each RES, it is possible to find the following tabs, which are filled if the related information is available:

- Generic Information: the technology is detailed with a brief description and information on its application scale (Building/District)
- Energy Power: the amount of energy that can be produced by such technology
- Installation constraints
- Technical Information: Specific technical information on the analysed technology is reported, such as the technology's efficiency
- Application: this section refers to the main types of devices, which can be used for implementing a specific RES. For example, for the RES "Photovoltaic solar panel (PV)" it is possible to choose among five types of PV devices: PV cells included into glazing, Roof-mounted panels, PV roof tiles, Panels sited on the ground, PV modules incorporated into walls or used on building facades for shading
- On the basis of the application that a technology can have, the building element on which the technology can have an impact is specified (Overall building, Windows, Ceilings, Internal walls, External walls, Roofs, Shading devices, Installations, etc.)
- Advantages in using such RES
- Disadvantages
- Type of fuel

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

- Cost
- District information: note on the application of the analysed technology at district scale
- Historic district context: in this section all the information regarding the implementation feasibility of the analysed technology for an historic district is reported
- Indicators

2) Renewable Energy Systems (RES) - Storage

By clicking on "Renewable Energy Systems (RES) - storage" in the index page, it is possible to access all the items on thermal energy storage systems. For each Seasonal Thermal Energy Storage (STES), it is possible to find the following tabs, which can be filled if the related information is available:

- Generic Information: the technology is detailed with a brief description and main technical information
- Installation constraints
- Advantages
- Disadvantages
- Cost
- Historic district context: in this section all the information regarding the implementation feasibility of the analysed technology for an historic district is reported;
- Indicators.

3) District heating and cooling

By clicking on "District heating and cooling" in the index page, all the items available in the repository about district heating and cooling systems can be visualised. This section collects generic information in terms of market overview, components and achievable benefits. Additionally, detailed information on solar thermal, geothermal and biomass systems is reported.

4) Complementary Tools

Two main types of tools have been identified with reference to applications in the Renewable Energy technology field. These tools are:

- Renewable energy evaluation tool used in preliminary analyses in order to facilitate decision making for people involved in the renewable energy industry.
- Renewable energy monitoring tool: measuring instruments for monitoring the energy flows from and to a renewable energy source and checking the correct operation of renewable energy technologies.

Climate analysis - Passive retrofitting solutions

For each European climate zone, a registered user can visualise information regarding the regions that belong to the analysed climate zone, the passive strategies that can be implemented in such climate zone, and the main weather characteristics.

Best Practice

By clicking on "Best practices" in the index page, a registered user can access the items on the identified best practices, downloadable in pdf format selecting the button "Best practices download". Moreover, it is possible to visualise for each best practice some further information with reference to the European climate zone where the best practices were developed, and the typology of the applied technologies.

Indicator List

The categorisation and list of indicators that have been used to evaluate the retrofitting solutions and RES technologies is reported as follows:

- Constraints: Impact on historic significance (Visual); Impact on historic significance (Physical); Impact on historic significance (Spatial)
- Habitability: Impact on thermal comfort; Impact on visual comfort; Impact on acoustic comfort; Impact on indoor air quality; Impact on electrical energy saving

- Economic feasibility: Cost
- Energy saving estimation, in terms of percentage reduction of the demand; Air change (winter); Window frame area; G-value; Shading factor; U-value walls; U-value roofs; Primary energy consumption / CO_2 emissions.

For each retrofitting measure and RES technology, a registered user can visualise the provided values related to such indicators. In particular, for the indicators "Constraints", "Habitability" and "Economic feasibility" the values vary from 0 to 4 with the following meanings:

- 0 - No impact
- 1 - Low impact
- 2 - Medium-Low impact
- 3 - Medium-high impact
- 4 - High impact

2.2 RENEWABLE ENERGY INTEGRATION

Historic buildings are the trademark of numerous European cities, towns and villages. There are different options that can be used to establish suitable ways to balance building protection requirements with the need for optimised energy efficiency as well as to increase the share of renewable energies - from design to technology and materials and different levels of integration.

There are many available strategies and technologies that can be applied to reduce energy demand and switch to sustainable energy solutions for historic buildings and districts. This requires close cooperation between experts who deal with historic buildings, energy efficiency and renewable energy systems. This chapter gives an overview of the different steps which are required to achieve more energy efficiency and use of renewable energy sources (RES) in historic districts.

First step: Energy demand analysis

The first step towards achieving energy savings together with the integration of renewable energies in an urban district is to undertake an analysis of the energy demand of every building. Demand analysis is a disaggregated, end-use based approach for modelling the requirements for final energy consumption in an area or district.

This includes the current energy demand for heating and cooling, as well as electricity demand for domestic and commercial buildings in the historic district. Different kinds of data have to be identified for a whole district. In order to estimate the annual heating demand of residential and commercial buildings, they have to be classified in the data base according to their age and constructional type. In the case of a historic city centre most buildings are typically associated to older building age classes. It is recommended to check the construction ages of the residential buildings thoroughly, since the building age classes are an important characteristic in order to estimate the energy-efficient properties of a building.

Second step: Reducing energy use and increasing energy efficiency

Each European city has its own historic districts with its characteristic buildings, road systems and places, which create its typical identity. Today it is an outstanding achievement in the field of heritage conservation to save the historic architecture in these districts. As with other interventions in the field of cultural heritage, energy efficient rehabilitation needs an individual approach, tailored to the specific buildings and/or district, according to their singular characteristics and climate conditions. Allowing for the reality that a large number of technologies and technical solutions are potentially available for energy efficient interventions in

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

historic cities, specific solutions must be selected on an individual bases, both at building and district level, in order to integrate them in a specific energy efficiency rehabilitation project.
An effective and the most obvious option of energy efficient renovation is the building fabric: the roof, windows and external walls, e.g. by internal insulation. In case of the Santiago de Compostela case study an overall reduction potential of around 18% could be identified.

Example: Insulation of the roof of a typical building in Santiago de Compostela
The roofs of traditional houses in Santiago de Compostela are typically hipped and pitched tiled roofs. Many houses possess additional elements like roof gardens, roof houses and dormers.

Thermal insulation of the roof can be inserted in the space between as well as under the rafters. Further research shows that through an improvement by an insulation layer of 20 mm with a resulting U-value of 1 W/m²K, the heating demand can be reduced by around 14%. A thermal insulation of 40 mm leads to an U-value of 0.7 W/m²K, and reduces heating demand around 27%. Results are shown in Figure 5 accordingly.

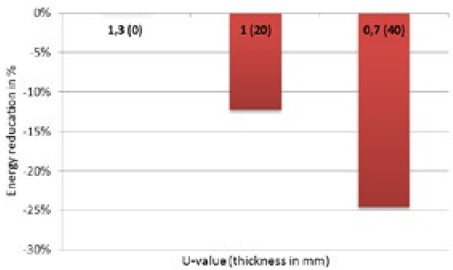


Figure 5: Reduction of energy demand in % according to the U-value of the roof.

Third step: Renewable energy integration on building level
As the third step, we have examined the renewable energy potential for historic districts. For this, we have examined the potentials for solar energy, biomass, near surface geothermal energy, waste heat, wind, water and deep geothermal energy, recognizing that local circumstances will influence decisions concerning the suitability of these different technologies. Solar energy is a renewable energy source with a significant potential to be used to generate thermal and electrical energy in buildings and urban districts, and in consequence to meet the daily demand through integrating different technologies and systems in the roofs of buildings. The applicability of these technologies to any specific historic district will, however, also be conditioned by the impact they will have on the heritage significance of the district. Mini solar panels which can be simply clipped into the respective roof shingles (Figure 6) can be a solution to address this conflict.

Figure 6: Solar tiles (Source: Bluenergy-ag.net)

The architectural integration of renewable energy sources in a sensitive historic context or in historic buildings is very critical. It requires the study of the physical and the visual impacts of the technologies on the building as well as its surroundings. Particularly, it is necessary to define the design criteria for the equipment to protect the character and the appearance of the historic building and to take into account the reversibility of the intervention.
Biomass is also a renewable energy source – however, not unlimited, especially in cities. Only the public gardens are considered for contribution while household gardens are not because of their very small proportion. To measure the amount of biomass the seasonal growth of the existing surfaces is estimated by using data from the literature of grassland and plant types. Figure 7 displays primarily public green spaces producing green waste in different areas of the city Santiago de Compostela.

Example: Solar and biomass use at Abbaye de Fontevraud, France
This example is focused on self-sufficiency of renewable energy supply, and as such it achieves the additional advantage of energy security for the site. The installations have been carefully integrated into the complex, and thereby also protect the heritage significance of the complex at the urban district scale.

In April 2012, a major programme of conversion to renewable energy was commenced across the whole site, aimed at achieving 100% self-sufficiency in heating and electricity by means of a combination of biomass boilers (using wood from local forests) and photovoltaic cells. This has being achieved by the careful integration of new energy infrastructure within the complex, including two boilers each with 500kW capacity and 92 PV panels. The objectives identified in the programme of energy conversion have been to:

- Decrease the energy consumption by a factor of 2 compared to 2011
- Decrease the contribution to the greenhouse gas emissions by a factor of 4 compared to 2011
- Cover 90% of energy needs from renewable energy sources

Figure 7: Biomass analysis in Santiago de Compostela, Fraunhofer IBP

Fourth step: Renewable energy integration on district level
Another possibility and good solution is to integrate renewable energies using district heating systems. District heating and cooling systems consist of centralized heat or cold generation plants and piped networks to distribute the heat or cold to the consumers. The advantages of the centralized and grid oriented energy supply solution over building centred solutions are:

- The possibility to utilise waste heat, which is generated in the electricity production process, e.g. in combined heat and power plants.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

- The opportunity to run generation plants which are only economically feasible with high annual operational hours.
- The compensating effect of a larger number of consumers with time shifted power peak demands.
- The high flexibility in the choice of the used fuel.
- The utilisation of the higher performance figures of larger generation units.
- That no emissions are produced on the spot where the heating and cooling demand is, e.g. in urban areas.

Consequently district heating enables other technologies, such as combined heat and power, to realize its potential of lowering greenhouse gas emissions by recycling or reusing waste heat. Energy efficiency results not only through saving of fuel, but also in a consequent reduction of environmental pollution.
Plants based on renewable energy systems (RES) have to be integrated in a useful way into the generation system. This relates in particular to the required energy output (heat/electricity: peak load and base load), available temperature level, performance class, logistic issues, integration capability and the location in the district heating network. For additional generation plants (both RES and fossil), a detailed examination of the feasibility is required. Most important criteria are:

- The temperature of the new generation plants, that has to be matched to the supply temperature of the existing network
- The spatial proximity to a possible existing district heating network
- A sufficient nominal diameter for input of heat power from new generation plants
- Amount of differential pressure on the new location for integration
- Implementation of a hydraulic verification of the supply situation for integration at different locations
- Additional requirements: area connection to the electricity grid, transportation network and potential link with a gas network

In order to achieve the highest possible share of RES, the network has to be designed so that the lowest possible „barriers" for the integration of heat from renewable energy plants occur. In particular pressure and temperature levels should be as low as possible. The possibilities for the integration of RES in district heating networks in consideration of historic centre areas are examined below. The following fuels or suitable forms of RES are analysed:

- Wood-based biomass
- Geothermal energy
- Solarthermal energy
- Waste heat used by large scale heat pumps

Example: biomass use at Visby, Sweden

Visby is one of the seven EFFESUS case studies. The urban district renewable energy system serves most buildings in the town, with piped infrastructure inserted principally under the streets, and is supplied by wood chip burning plants sited outside the historic district. It offers a sound example for a self-contained small town served by surrounding land and forests.

Tools for the development renewable energy integration

Energy use as well as energy production has always enjoyed a geographical correspondence. Energy production facilities can be located in the geographical context of a district and energy demands can be assigned to an area. The distance between demand and supply has to be bridged by transportation, which as well demands infrastructure that occupies space. The planning and optimisation of transportation lines and grids is very close to the original core tasks of geographical information systems (GIS) in mapping and cartography: Avoiding unfavourable geographic conditions, long distances and disparities between demand and supply. Technical energy infrastructure, distribution grids and networks were part of the urban landscape as a matter of course and in its continuity they are hardly noticed anymore. Energy production sites were traditionally central large scale industrial facilities, with large local but marginal regional disturbance by visual appearance or pollutant emissions. With increasing shares of renewable energies inside cities and districts, the urban landscapes change. With the trend towards decentral production and the moving together of demand and supply, energy infrastructures become more visible because there are more scattered energy plants in the urban and open rural landscapes. At the same time the discussion on energy supply and efficiency becomes increasingly important. The visual impact of renewable energy plants and the trade-off between the new technologies and the well-known familiar appearance of urban and rural environments occasionally lead to severe public conflicts.

This can be moderated by visualization as well as processing of objective information through maps derived from GIS systems. Therefore a good data acquisition and documentation is fundamental for a good display of the investigated energy system in a GIS. Regarding the energy system, a three column structure should be followed: energy demand, energy production and energy supply infrastructure. To enable a holistic picture of the system in focus it is necessary to include some information from all the energy sectors including their demand profiles, the different energy sources as well as the potentials to use renewable energy sources. The objective is to identify all energy-related data bases and their spatial distribution on the considered area or district. This includes:

Energy demand

- Location-based heat demand of the historic and non-historic building stock
- Historic centres and districts: identification and characterisation of non-residential buildings
- Total power consumption of the community/district

Energy infrastructure

- District level: existing heating and gas distribution systems, heating-, combined heat and power plants, etc.
- Building level: Equipment for the individual heat supply, for example type of boilers, required temperature levels of existing radiators, etc.

Geographic data

- Aerial photographs, urban plans such as land use plans and development plans
- Historic monuments classification, e.g. though questionnaires / historical records
- Further information through site inspections or local knowledge of building physics experts, monument conservators

Conclusion

The simplest solution to increase the share of RES is to reduce the energy demand, especially the heating and electricity demand as a first

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

step. New windows and roof insulation with a better U-value lead to a substantial reduction of the heat demand in our investigated examples. Renewable energies like solar energy, geothermal and biomass can increase the renewable energy share, which can be increased to more than 50 to 80 per cent by additional thermal and electrical storages.
Because historic buildings have a restricted potential for the application of energy-efficient retrofit measures other measures shall be considered in order to increase the renewable energy share. Heat pumps are a further solution, which could be applicable to generate heat efficiently if a sufficient amount of electricity is available from renewable sources, for example from wind on the coast line.

Urban and energy mapping by geographical information systems (GIS) can help to find solutions and the appropriate space for solar energy, the biomass potential or the distance between power plants and storages. Finally GIS allows giving the user an overall picture of the possibilities and different technological solutions to integrate and increase the use of renewable energies in historic districts.

2.3 INDOOR CLIMATE SOLUTIONS

A comfortable indoor climate is a necessary condition for the use of any type of building. In historic buildings with poor insulation, high thermal mass and high air exchange, traditional temperature based climate controls may not be sufficient to provide both comfort and energy efficiency. In historic buildings, energy efficiency is not only about reducing energy consumption but also about improving the indoor environment.

The core of the proposed solution is to control the indoor climate with respect to comfort indices. The target comfort levels of the different parameters are pre-set and then adjusted through user feedback. In addition, CO_2 monitoring, scheduling of the set points of the parameters in function of the occupation planning, can be used for further improvements.

Comfort based control
The proposed solution is based on the main principle that comfort should control the HVAC systems, not vice versa.

The comfort is indicated by the percentage of persons dissatisfied (PPD), or predicted mean vote (PMV) criteria, and by user input. The calculation of the thermal comfort through the PMV or the Adaptive Comfort Model is made according to ISO 7730 [1]. In addition, to selecting the initial comfort levels, the user should be able to control the target comfort level continuously by a simple user interface. In order to keep the energy consumption down, it is necessary that this strategy is coupled with feedback to the users on energy and power consumption.

CO_2 based control
CO_2 control can be a complement to the scheduling system. The scheduling system can set comfort criteria, and then the CO_2 measurements can control the air exchanges. The same actions could be undertaken for an active and smart control management of Indoor Air Quality: the threshold limits of specifically selected pollutants should be included in the software that drives the ventilation system.

Weather based control

Weather forecasting and weather monitoring can be used to aid proactive indoor climate control allowing for reduced energy demand, lower peak power demand and improved comfort capitalizing on the high thermal mass of historic buildings.

In buildings with small thermal inertia, it might be too late to start to regulate the systems when the temperature actually starts to change. By the use of weather forecasts, it can be done in advance to keep the comfort within the given criteria and to minimize the peak power demand. In buildings with large thermal inertia, it is sufficient to monitor the rate of change in outdoor temperature. This is easier and often cheaper than using weather forecasts. When the system registers a rapid change in outdoor temperature, it will predict the impact on comfort inside the building with a time delay due to the inertia of the building.

Lighting control systems and strategies

Lighting control strategies provide additional cost-savings through real time pricing and load shedding. Lighting Management Systems (LMS) allow building operators to integrate lighting systems with other building services such as heating, cooling and ventilation, in order to achieve a global energy approach for the whole building.

Several lighting control strategies exist to improve the energy efficiency [2].

1. The Predicted Occupancy Control Strategy (POCS) is used to reduce the operating hours of the lighting installation. It generates energy savings by turning lighting on and off on a preset daily time schedule. Schedules usually vary on a daily basis according to the building occupancy. No sensors are needed, but the controllers in the lighting management system need to be programmed.
2. Real Occupancy Control Strategy (ROCS) limits the operation time of the lighting system based on the occupancy period of a space. Compared to the predicted occupancy control, it does not operate by a pre-established time schedule. The system detects when the room is occupied and then turns the lights on. If the system does not detect any activity in the room, it considers the room as unoccupied and turns the lights off. Here occupancy sensors need to be installed and connected with the controllers of the lighting management system. Real Occupancy Control Strategies are best used in applications where occupancy does not follow a set schedule and is not predictable.
3. The Constant Illuminance Control Strategy (CICS) takes into account the ageing of the lighting system in the room. It compensates the initial oversizing of the lighting system introduced by the use of the maintenance factor (MF) at the design stage. It uses a photocell to measure the lighting level within a space, or determines the predicted depreciation (ageing) of the lighting level.
4. The Daylight Harvesting Control Strategy (DHCS) allows facilities to reduce lighting energy consumption by using daylight, supplementing it with artificial lighting as needed to maintain the required lighting level. It uses a photocell to measure the lighting level within a space, on a surface, or at a specific point. If the light level is too high, the system's controller reduces the lumen output of the light sources. If the light level is too low, the controller increases the lumen output of the light sources. Sensors are often used in large areas, each controlling a separate group of lights in order to maintain a uniform lighting level throughout the area. Daylight harvesting systems are generally used in spaces that have relatively wide areas of windows or skylights.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

Ventilation and air conditioning systems

Whereas in the past, ventilation was automatically linked to indoor air quality control, there is now a growing interest in ventilation as part of an energy efficient strategy for achieving thermal comfort in summer. Historic buildings were often more ventilated than strictly necessary because of loose-fitting doors, windows and other openings. In addition, open fires created generous rates of exhaust ventilation through chimneys at times when condensation risk might otherwise have been high. For this reason, historic buildings usually need more air conditioning and ventilation than modern ones. Nevertheless, if ventilation of a historic building is reduced too much through retrofitting initiatives, condensation, mould and fungal growth may occur, leading to deterioration of the fabric and contents, and possibly health problems will arise for occupants. Great care is therefore required in selecting an appropriate ventilation rate for a historic building.

The energy consumption of ventilation systems is obtained as a function of air flow rate, pressure drop, efficiency and expected useful life. Energy savings can be achieved through targeted influence of each parameter. Active demand-controlled ventilation and air conditioning systems are helpful to measure and control all these parameters depending on the demand. Ventilation control strategies provide just the right amount of outside air that is needed by the occupants, dependent on conditions like air quality, temperature, and energy load.

To reduce the energy consumption of active ventilation systems as much as possible, different approaches are needed.

1) Room level: the ventilation system, typically part of the heating and cooling system, will adjust a damper to let more or less outside air into the building depending on what the sensor detects.

- Air volume can be reduced „time based" or „occupancy based" in function of changes in occupancy or thermal loads
- Quality control, based on CO_2 sensors
- Temperature control
- Individual room control, with information exchange on distribution and/or generation level with regarding of occupancy, influence of interior sources of heat (people, lighting, equipment) and other signals like temperature and air humidity.

2) Air handling unit: on this level, one can control air volume or pressure to reduce energy consumption, and some control systems such as overheating protection.

Algorithms for comfort based indoor climate control

A control algorithm is a mathematical or logical function that, based on the difference between a target condition and an actual condition, provides a signal to the Heating Ventilation and Air Conditioning (HVAC) system.

First, an initial comfort level is chosen, and then the user can give feedback to the Building Management System (BMS) to adjust the preferred level. ISO 7730 [1] uses an energy ranking scheme, which ranks the HVAC control actions according to energy use. The most energy-saving action is first, and the action which increases the energy use is at the bottom. If given comfort criteria are not fulfilled, the Building Management System will try to activate the actions from the energy ranking, always starting from the top. If the action improves the comfort, the action takes place, if the comfort level worsens, the action will not take place. The BMS follows

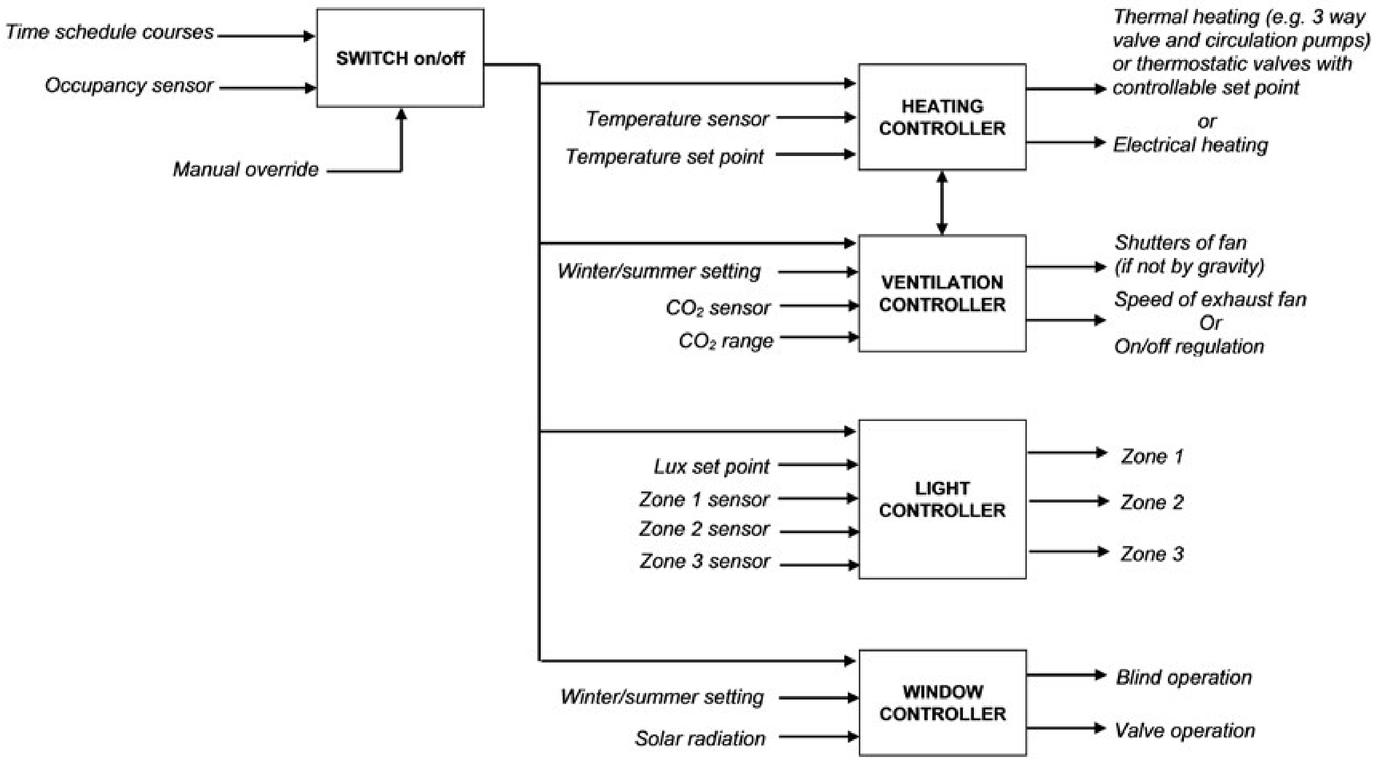


Figure 8: Simplified control scheme of the BMS installed at the Budapest University of Technology and Economics

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

the ranking until the comfort criteria are fulfilled. The weather control will override the comfort control when needed.
Scheduling will also override the basic comfort control by setting new target levels when the room/building is not in use.

As far as CO_2 and pollutants are concerned, in conditions where the sensors measure values close to or above the threshold limits, the ventilation rate must be increased; in the opposite case, when the contaminant level decreases, the ventilation rate must be reduced to the minimum background air change level for that type of space.

Algorithms for illumination control are essentially based on two strategies: occupancy control and daylight harvesting. Occupancy sensors drive the lighting controllers in an on/off mode. Sometimes a minimum lighting level is maintained for safety reasons. Also a timer is sometimes included to avoid lights being unduly switched off when the occupancy sensor does not sense any movement.
Illumination level sensors usually drive the light source dimmers, adjusting their outputs to a given set point via a simple feedback loop. Often, large rooms or areas are split up into zones. An illumination level sensor controls the lamps in each of these zones.

Illumination management systems, as part of a building management system, nowadays allow the programming of several illumination scenarios. By doing so, the illumination level can be adapted to the needed level defined by that scenario, avoiding the use of more light than is necessary for the programmed scenario.

Strategies for energy conservation in HVAC systems are usually directly integrated into the control systems of the HVAC systems. The algorithms differ in function of the HVAC system itself and the strategy selected.

The chosen control strategies of respectively indoor air quality (IAQ), thermal comfort, illumination and HVAC finally need to be integrated in a Building Management System. Interactions between the respective controllers can become very complex and priorities will need to be established to manage the whole set up.

The example of the Budapest case study developed within EFFESUS is presented in Figure 8.

References:

[1] ISO 7730:2005 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, International Standards Organization, Geneva, 2005.
[2] IEA (2010). Energy Conservation in Buildings & Community Systems, Annex 45 Energy-efficient future electric lighting for buildings.

3 EFFESUS INNOVATIONS FOR ENVELOPE RETROFITTING OF HISTORIC BUILDINGS

3. EFFESUS INNOVATIONS FOR ENVELOPE RETROFITTING OF HISTORIC BUILDINGS

In historic buildings, as in most existing buildings, the building envelope is crucial for their energy performance: walls are often thick, but they nevertheless conduct heat very well; single glazed windows lead to very low surface temperature, and are often not airtight at all. However, the criteria to be considered when selecting the appropriate retrofit measures go beyond the potential increase in energy performance; they also include the reversibility of the intervention, the possibility to conserve original material and, importantly, the aesthetic impact that a retrofit intervention might have.

Within the EFFESUS project, several pioneering small and medium enterprises (SMEs) together with research partners have developed four innovative solutions to improve the envelope performance specifically in historic buildings: aerogel insulation, insulating mortar, radiant reflective coating, and upgraded original windows.

The developed aerogel insulation is blown into the spaces, just a few centimetres in depth, of an existing wall structure – for example behind the "plaster on laths" finishing in Scottish tenement houses or wooden panelling in Alpine farm houses – thereby retaining the original surfaces and avoiding the loss of both original material and the evidence of traditional building techniques. Even the thin aerogel layer can reduce the heat transfer to about one third of the original wall, as has been shown both in the stone-wall prototype tested at INTENT lab and on-site in the Glasgow case study.

Appropriate for both the interior and exterior – and often uneven – surfaces of historic buildings is the formulated insulation mortar. Based on natural hydraulic lime (NHL5), it is compatible with most historic structures; the polystyrene insulation filler makes it both energetically and economically very interesting. It has successfully passed the driving rain and temperature stress tests and was examined outdoors in Holzkirchen and indoors in the case study building Benediktbeuern.

Interesting for historic buildings in hot climates is the radiant reflective coating. Thanks to the high infrared (IR) reflection it reduces the amount of solar heat absorbed by the envelope – be it the exterior wall or the roof – and thus reduces the cooling need within the building without intrusive impact on the building fabric. Even though the aim to get a both reversible and transparent product has not yet been achieved, the application simulations show what can be expected in future in terms of overall-year energy performance improvement.

For original windows, a number of improvement options ranging from thermal shading and low-emissivity films, to thin multilayered glazing, and the concept for a supply air window, have been investigated. They can be applied individually or in combination; for each window and building the right solution has to be selected taking a balanced account of all issues.

The tests of the products in laboratory and outdoor test-stands served both to demonstrate their durability and their actual performance in terms of contribution to reduced energy demand in different situations. So was for example a 1.5x1.5m mock-up of a historic stone wall built up and its thermal performance measured in INTENT lab. The lab tests of the IR coating have been complemented with building simulations in order to determine the most promising applications. The products were also applied at the different EFFESUS case studies, which allowed not only to measure actual on-site performance, but also to gain valuable experience on practical issues of applicability and ease of handling.

This section is concluded with a look at the applicability of the EFFESUS innovations from a restorer's perspective.

3.1. AEROGEL INSULATION

The A Proctor Group Ltd have developed Spacefill, a unique, thin, highly efficient insulation for use in historic buildings with existing solid wall construction where lath and plaster finishes are present. The ability to insert high performance insulation into an existing cavity is highly attractive due to the fact that the removal of the lath and plaster is expensive, disruptive to the homeowner and can also mean the removal of decorative plasterwork such as cornices etc.

Figure 9: Spacefill in situ, after it had been blown into the cavity.

Spacefill utilises this empty space between the masonry wall and plaster finish, so does not encroach on valuable room space. As it uses existing installation methods, this is also relatively simple, with minimal redecoration required. This would be a major advantage to the homeowner.

Spacefill is derived from aerogel insulation which has a class leading thermal conductivity, but is also breathable and water resistant – all properties which are ideal for cavity insulation. Ways in which to install this insulation using existing blowing in techniques and equipment have been researched.

Various cutting trials were carried out on the raw material in order to achieve a suitable size which could be used. After several trials, 5mm cubes were deemed to be the most suitable to produce the Spacefill insulation.

Testing was carried out to determine the thermal conductivity of the Spacefill at a specific density. The optimum density was found to be 70kg/m^3 and produced a thermal conductivity of 0.0255W(mK). Other testing is summarised below:

Fire Performance (50kg/m^3 & 70kg/m^3)	EN 11925-2	No ignition*
Moisture Absorption	EN1609 – to be <1	0.11344
Vapour Transmission	EN 14064-1	μ=1

* Fire result is very positive: The material could easily reach class E (requirement: 5 positive tests with test duration 15 seconds). With the positive behaviour after 30 seconds test duration even higher classes like D, C, B or A2 are feasible. To prove these classes further tests are required which includes SBI-tests according to EN 13823.

Table 1: Results of aerogel insulation testing

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

A full year's monitoring provides invaluable information, recording real-time performance over all conditions and seasons. This can then be used to assess suitability and expected performance in similar applications. This is a unique test situation which will allow a product to be developed that can be used in historic buildings without altering the look of the building, or encroaching into room space.

A yearlong trial of the Spacefill has been carried out in Glasgow, where a property has been taken over to conduct the trial. This property is a second storey, mid-terraced tenement in the Yoker area of Glasgow. The external wall is of sandstone construction, which is typical of historic buildings in this area. This was identified as ideal for the retrofitting of the Spacefill blown-in insulation.

Figure 10: Installation of aerogel fibre insulation into test panels

The aim was to fill the cavity behind the plasterboard/lath and plaster in one room and then be able to compare the thermal performance between the uninsulated room and the insulated room. The installation, carried out in March 2015, was successful.
On-site trials have proved successful in terms of installation, and the installer has commented that Spacefill was the best insulation they have used to fill a cavity – better than bead, foam or fibre. There was dust generation; however, this was only evident on the external wall side and there was very little dust generated on the room side.
Monitoring equipment was installed and data collected over the entire year. At the time of removal, thermal comfort readings as well as thermal imaging were taken in both rooms. This indicated that the cavity has been well filled.

The next stage is to remove the blown-in insulation, as part of the remit that any measures should be reversible.

3.2 INSULATION MORTAR

The majority of the building stock from before 1900 was erected with natural hydraulic lime-based mortars in solid masonry. Due to the low modulus of elasticity of lime-based mortars, there has never been a need for dilation joints in old masonry structures. Changes in shape as a result of expansion and contraction, due to hot/cold cycles, could be "followed" by these masonry structures without damage. Moreover, lime-based mortars have a high vapour transmission rate, beneficial to the breathing capacity of monolithic historic masonry. These two most important characteristics

have been taken into account when selecting the binder in EFFESUS. ISOCAL is an insulating render, designed and developed for use on masonry in cultural heritage buildings as well as for retrofitting of historic urban districts. It is a natural hydraulic lime NHL5. This specific quality of lime allows the render to be used for inside as well as outside applications due to its resistance against mechanical and environmental influences.
The selected aggregates, fillers and additives not only provide a low lambda-value, a high vapour transmission rate and good mechanical characteristics, but are also compatible with historic mineral substrates. ISOCAL can be applied by any skilled plasterer.

For the development within EFFESUS project, Bofimex selected a NHL5 lime. Amongst other hydraulic lime types this binder has the best initial and natural strength development, specifically needed when a high degree of insulating filler is chosen. Several insulating fillers were reviewed and checked for their suitability. Finally, it was decided to rely on Expanded Polystyrene (EPS) as a well-known insulating agent in buildings. It has the advantage of an easy use in mortar formulation together with a good cohesion/coherence with the mortar binder, and the product is broadly available on a commercial scale with corresponding low product costs.
The new mortar formulation was processed and tuned in a way that it has a good workability and applicability. This is important for a willing acceptance by professional craftsmen/plasterers. First application tests proved that the material can easily be applied up to a one layer thickness of at least 3 cm. Because of its composition based on NHL binder and a layer thickness of 3 cm or more, this base mortar layer requires a longer drying time (approx. seven days) before finishing layers can be applied.

The mortar is applied in situ as an uninterrupted skin on the substrate, thus eliminating thermal bridges. In many cases of old masonry, the substrate that needs to receive an ISOCAL render can be inhomogeneous (different kind of bricks/stones have been used) and contaminated by salts (chlorides, nitrates), rain and/or wind-born pollutants. In these cases it is recommended to prepare the substrate with a thin, almost transparent, brush-on coat of primer mortar. This application homogenises the substrate before receiving the ISOCAL render, thus ensuring sufficient adherence between ISOCAL and original substrate. The consolidation mortar has the same NHL5 binder as ISOCAL, assuring an identical E-modulus. Furthermore, this mortar has no additives that might diminish the high vapour transmission rate.
Like all insulating renders, ISOCAL cannot remain visually exposed for physical and aesthetical reasons. ISOCAL should receive a finishing plaster at least seven days after application. This finishing not only provides the render with an acceptable aesthetical appearance and a good weather protection, it also improves the impact strength of the total system. If advanced impact strength is required, for example against bike-parking or ladder-placing, it is recommended to introduce an alkaline resistant coated glass mesh (6 x 6mm or 4 x 4mm) in the finishing layer. The finishing mortar is available in a range of natural colours, varying from off-white to amber, ochre and brick-red.
If desired for aesthetical reasons, the finishing layer can receive a coating afterwards. Due to the breathing capacity of the insulating ISOCAL system it is strictly advised to choose mineral paints e.g. lime wash or pure mineral paint. Never use synthetic paints (acrylates, alkyds, epoxies, polyurethanes, etc.) here because they will destroy the render system due to their vapour tight character.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

There might be a technical reason to apply a protection against harsh weather conditions like wind driven rain. It is strongly advised not to use silane, siloxane or silicone based water repellent coatings as they will enhance salt crystallisation behind the treatment and thus destroy the render system. The only generic type product that can be applied for this demand is an emulsion based on natural bee wax. In certain concentrations this type of product also performs as an anti-graffity coating in a system of two coats.

The experimental campaign carried out within EFFESUS allowed us to develop a technical data sheet with all relevant product characteristics. Besides, the technical durability of the ISOCAL plaster system was determined in an EOTA (European Organisation for Technical Approvals) test wall chamber based on the assessment procedures for External Thermal Insulation Composite System (ETICS), according to European Technical Approval Guidelines (ETAG004). This was accompanied by a field test under real climate conditions at Holzkirchen in Germany. In both procedures the ISOCAL proved to be durable with sufficient bonding, cohesion and weather resistance. The lambda value of 0,0682 W/(mK) is better than the ones known for standard (lime-based) plaster materials.

To prove its contribution to the energy performance of historic buildings, the mortar system was applied in a case study. The building selected for that, named "Alte Schäfflerei", is dated from around 1760 and part of the craftsmen court of the monastery in Benediktbeuern. For the specific demonstration within the EFFESUS project, one room on the ground floor in the northern part of the building was selected. The floor surface is about 16 m². It has outside walls with a thickness of 60 cm, and a window exposed to West. The walls consist of masonry of a mixture of

Figure 11: Application test of the insulating mortar ISOCAL

Figure 12: The testing of the insulating mortar ISOCAL at the case study in Benediktbeuern

stone and lime/clay bricks, with existing external and internal plaster layers. The room has a double-glazing window from the 1990s.

The new thermal insulating mortar ISOCAL with an NHL-based finish plaster was applied in June 2014 on the inner surface of the exterior wall facing west, which is about 8m^2. In order to evaluate thermal performance of the new insulating mortar, the data recorded before the intervention were compared with the ones collected after the application of the mortar. In 2013/14 a water heating system was running, whilst since August 2014 a radiant heating system was installed; both have a controlling reference point for internal air temperature at 20°C. In particular, considering the same internal boundary conditions (e.g. the activation of the heating system), two different periods can be overlapped:

- 31st July – 17th August 2013 (before intervention) vs. 2014 (after intervention) when the heating system was turned off;
- 1st October – 28th February 2013/14 (before intervention) vs. 2014/15 (after intervention) when the heating system was turned on.

In the heating periods (1st October – 28th February 2013/14 vs. 2014/15), the environmental conditions were very similar. In addition, the indoor air temperature remained very constant thanks to the heating system, which maintained the temperature inside the room around 20°C in both years. The difference between the external and internal surface temperatures increased in 2014 thanks to the thermal insulation of the mortar. In 2013, the average value of this difference was 12.3°C, which increased up to 13.8°C in 2014. In the heating period of 2014 the ISOCAL mortar layer accounted for 5°C of this 13.8°C temperature difference (the same rate as in the summer period). Considering the thickness of the ISOCAL mortar layer with respect to the total thickness of the wall (60cm), the reduction of 5.0°C on average in only 3cm could be considered as a good result.

The results in both summer periods (31st July – 17th August 2013 vs. 2014) also showed the same thermal effect. The thermal insulation of ISOCAL mortar was proved by the monitoring data recorded in Benediktbeuern, in particular by: the higher difference between external and internal wall surface temperatures, the decrease of the heat flux, and consequently of the conductance and transmittance of the insulated wall, the improvement of the indoor comfort, as well as the reduction of electrical demand and peak load needed for heating.

To summarise, the important advantages of ISOCAL are that it:

- Can be used for both indoor and outdoor application
- Provides excellent thermal insulating characteristics
- Is applicable on mineral substrates such as natural stone, brick, ceramic block, old intact mineral render/plaster and concrete
- It can be applied by hand or sprayed
- Is light weight: up to 3 cm layer thickness in one application
- Is a ready-to-use product

ISOCAL should, in all cases, be finished with a compatible finish plaster.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

3.3. RADIANT REFLECTIVE COATINGS

Radiant reflective coating, without intrusive impact on the building fabric, can improve the envelope performance. EFFESUS aimed therefore at developing a coating with high Infrared (IR) reflection, which reduces the amount of solar heat absorbed by the envelope – be it the exterior wall or the roof – and thus cuts the cooling needs within the building.

Such a coating, if it should be applied on historic buildings, has to meet not only energetic but a much wider range of requirements. It has to be:

- Physically and chemically compatible
- Durable
- Aesthetically acceptable
- Reversible
- Non-intrusive

The chemical nature of a coating depends mainly on the specific needs of the substrates on to which it will be applied and on the desired durability of the coating. Thus, in order to design a suitable new coating from the point of view of its ideal properties, firstly, a selection of four targeted substrates was made.

Amongst the most common building materials of European Cultural Heritage there are sandstones, limestones, bricks, travertines, granites, marbles and mortars. These materials present some specific characteristics, namely:

- They are porous to a greater or lesser extent, so decay agents can enter into the substrate easily;
- When the buildings are located in urban, industrial or marine environments, they are subjected to the harmful action of contaminants, salts, etc;
- They are weathered according to their age, and may present different decay forms such as disaggregation, decolouration, etc.

The aim was to select materials with a variety of porosity and pore size values. Thus two building stone typologies were selected together with brick and lime mortar to complete a representative selection of the porous materials that can be found in the Cultural Heritage buildings of Europe. The four substrates of interest were characterised in order to determine the following properties:

- Physical properties: substrate chemical characterisation before coating application (mineralogical analysis through X-Ray Diffraction, petrographic examination, density porosimetry), colorimetry before and after the coating application and adhesion after coating application.
- Hygric properties: capillary water absorption, absorption at atmospheric pressure, water vapour permeability.
- Water contact angle.
- Penetration into substrate, coating appearance, reversibility through Scanning electron microscope analysis.
- Optical properties (Infrared reflectance according to the Standard ASTM E-903) and thermal behaviour (internal in-house test based on IR lamps).
- Durability: salt crystallization, frost/thaw cycles and ultra-violet (UV) light and condensation.

These tests allowed the physical and hygric properties of original substrate and the substrate to be studied after the application of the coating. In addition, some tests were repeated after the removal of the coating in order to show that the developed solution is truly reversible and does not alter the original condition of the substrate. Firstly, a full substrate physical-chemical characterization was carried out and a selection of the most important results is shown in Table 2.

Substrate	Porosity (%)	Bulk density (g/cm³)	Average pore Ø (µm)
Villamayor sandstone	26.26	1.79	0.585
Istanbul stone	9.92	2.38	0.288
Solid clay brick	18.46	2.04	2.31
Lime mortar	43.00	1.39	2.125

Table 2: Physical-chemical characterisation of the substrates

Secondly, a selection of best-selling commercial additives, mainly based on ceramic spheres and nanoparticles taking into account the final application of IR reflecting properties, was made. The nanoparticles selection included Aluminum Zinc Oxide (AZO), Zinc Oxide (ZnO), Titanium dioxide (TiO_2), Fluor Tin Oxide (FTO), Tin Oxide (SnO_2) and Indium Tin Oxide (ITO). Two different coatings, namely as Coating 1 and Coating 2, were synthetized by the project partners ACCIONA Infrastructures and Advanced Management Solutions Ltd. (AMS) using two different approaches.
Coating 1 was an inorganic coating fabricated using the sol-gel method. Coating 2 was based on a water base solution. Sol-gel reaction scheme is based on hydrolysis of various alkoxides forming respective silanols. This is followed by a condensation reaction occurring between silanols or between silanols and alkoxides. The sol-gel process involves evolution of inorganic networks through the formation of a colloidal suspension (sol) and gelation of the sol to form a network in a continuous liquid phase (gel). The most important advantage of sol-gel processing over conventional coating methods is the ability to precisely control the microstructure of the deposited film.
Different sol-gel coatings were obtained by means of incorporating one (or some) of the nanoparticles and additives mentioned above. In the case of Coating 2, different formulations were also developed, mostly based on ITO in various granularities and concentrations.
In order to ensure the reversibility of the IR reflective system, a reversible primer was applied as base coat prior to the addition of the top coat IR reflective coating. After testing and evaluating different candidate primers widely used in historic buildings, Paraloid B87 was selected. This is a thermoplastic resin and an excellent adhesive for archaeological materials as well as a durable and non-yellowing acrylic resin. It can be

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

described chemically as an ethyl-methacrylate copolymer, which can be dissolved in acetone – which is friendlier than other solvents.

As a result of the experimental work and the testing campaign, two new IR reflective coatings were obtained:

1. Reversible, IR reflective coating for all substrates tested, but non-transparent.
2. Transparent, reversible and IR reflective coating for lime mortar and metal.

Both coatings showed excellent results regarding the hygric properties (capillary water absorption, absorption at atmospheric pressure, water vapour permeability) and durability.

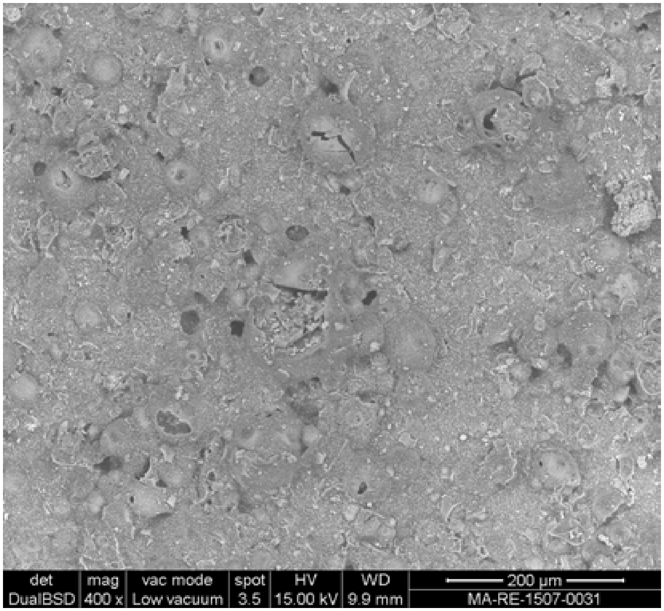


Figure 13: SEM image of Paraloid + Coating 1

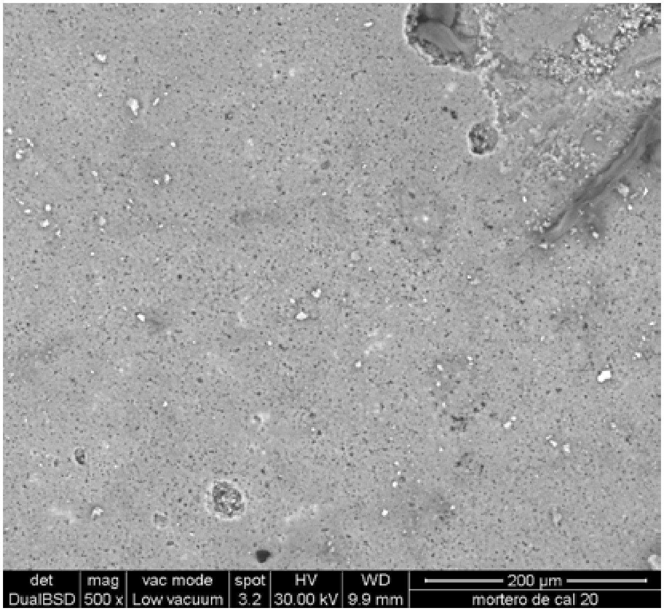


Figure 14: SEM image of Paraloid +Coating 2

It was agreed, firstly, to assess and determine the thermal performance of the first coating applied on a large scale wall in a guarded hot box called INTENT (Integrated Envelope Testing facility), and secondly, to demonstrate the second coating in a real building in Istanbul.

Finally, the performance of the new exterior radiant reflective coating for cultural heritage applications was demonstrated in the Istanbul case study. The building selected for the demonstration is located in Kallavi Street, in Beyoglu District and is owned by Beyoglu Municipality. The demonstration was managed by the local partner, SAMPASŞ Nanotechnology.

The intervention consisted of the application of the coatings on different substrates placed on a parapet wall at the top of the building. The coatings were not applied directly on the facade of the building as their removal, on such a porous stone, could at this stage not be guaranteed. Furthermore the monitoring of the energy performance on wall and room level would have been difficult, considering the influence of very large window areas of the case study building and the difficulty to impose equivalent user behaviour in different rooms.

Figure 15: General view of the parapet wall with the samples installed at the case study building in Istanbul.

3.4 UPGRADING OF HISTORIC WINDOWS

Windows are important elements of the architecture of any building, and in cultural historic buildings their significance is heightened by the importance of their influence on the internal environment. Windows were originally the only way for daylight, fresh air and solar energy to enter heritage buildings and to ventilate out used air and excess humidity. They also provide views into and out of the building. Windows are such an integral part of architecture that their importance and design cannot be separated from their architectural style or design. Preserving the windows is therefore critical to the heritage value of the building as well as achieving a comfortable internal environment.

The current challenge is to reduce the environmental impact of windows by retrofitting them with energy efficiency measures without compromising their cultural and historical values. Windows in heritage buildings present a particular challenge as they were usually made with decorative timber profiles and single glazing, and it is often expensive to replicate their design and improve their performance without compromising their heritage value. Modern windows have been designed for low cost and low maintenance in materials which are usually inappropriate for historic buildings; the materials and manufacturing processes often result in large frame sections incompatible with historic window designs.

In this contribution several options of improving the thermal and moisture performance of a sample window will be presented. A box type double sash window is chosen since it is a common type in older buildings throughout northern Europe. By developing and investigating the options for this specific window, it has been considered that the strategies could be applied to other window types resulting in similar levels of improvement.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

In the initial stage of developing the window solutions, numerical modelling was used to predict the performance of the prototypes. In order for the results to be comparable and reliable, several computation standards were reviewed. It was decided to use more than one standard of numerical simulation in order to give the best information about the investigated options. The following performance criteria were defined for each solution (in brackets, the short name of applied standard is given, for full name please see references [1] – [5]): thermal performance (ISO 15099, ISO 10077-2); visual transmittance and G-value (ISO 15099, ISO 9050); and moisture analysis (certified passive house glazing and transparent components). Later calculations of thermal performance were validated by full-scale experiments. Measurements were carried out in a guarded hot box apparatus, according to procedures described in ISO 8990:1994 and ISO 12567-1:2010.
Additionally each solution was considered according to the following criteria:

- Aesthetic influence
- Reversibility
- Durability
- Maintenance
- Legislation capability, and
- Cost effectiveness

The application of each improvement option has been tested and investigated using a box-type original window as a starting point. Application of each solution to the base window resulted in five different prototypes:

Prototype 0 – "Original Window"
The prototype is a typical box-type window, consisting of two sashes separated by a 12cm wide air gap. It represents a significant advance in thermal comfort and insulation from previous windows with only a single piece of glass separating the interior from the exterior environment.

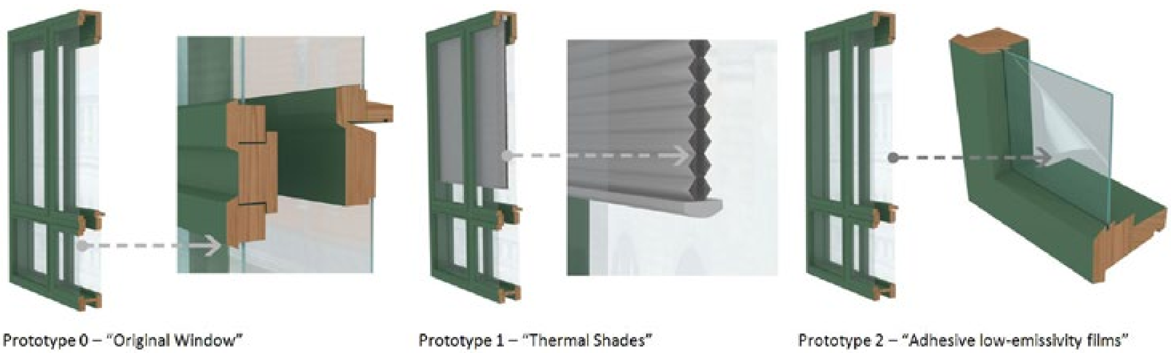
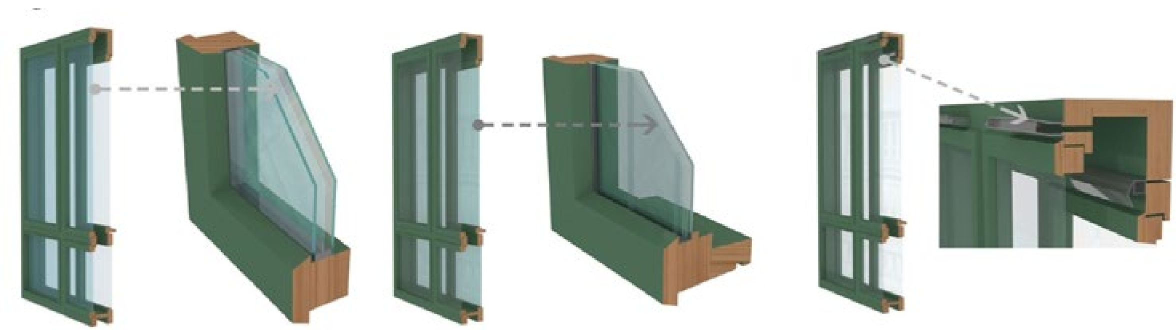


Figure 16: Window prototypes 0,1 and 2



Prototype 3 – "Multi-layered glazing"   Prototype 4 – "Air Sandwich"   Prototype 5 – "Supply Air Window"

Figure 17: Window prototypes 3, 4 and 5

Many different varieties of such window types exist, which are characteristic of the country or region and in some cases even for the decade of the building's construction. Prototype 0 provides a baseline of comparison for the calculations and measurements of the performance of the other prototypes.

Prototype 1 – "Thermal Shades"

This prototype includes thermal shades installed in the air gap between the glass layers in the box window. Thermal shades in this case are cellular shades (type: "cell in cell"), which adds thermal resistance to the window and reduces solar heat gain in the summer.

Prototype 2 – "Adhesive low-emissivity films"

This prototype uses adhesive plastic films with low emissivity properties. The advantage of this solution over low emissivity coatings on the glass surface is that those films can be added to the existing glass, while low emissivity coatings can only be applied during the manufacturing process.

Prototype 3 – "Multi-layered glazing"

This prototype uses insulated glazing units which include thin glass panes (glass thickness from 0.1 to 1 mm) in a multi-layered unit. Ultra-thin glass panes are used as the middle panes in a multi-layered glazed unit. This provides high insulation levels while keeping the overall unit lightweight and narrow. In some cases this allows the original design of the historic window (and frame) to be preserved while providing a substantial thermal improvement.

Prototype 4 – "Air Sandwich"

This prototype integrates a product called the "Air Sandwich", which consists of five transparent thin plastic layers glued to the original panes with plastic frames sealed with a secondary sealant. Increased thermal resistance of the air sandwich is due to multiple air gaps, which are created by thin plastic layers. Each air gap adds additional resistance by splitting air into small volumes and limiting size of convection loops. Moreover, multiple layers of material reduce radiation heat exchange – providing better thermal performance.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

Prototype 5 – "Supply Air Window"

This prototype uses specially designed valves which allows fresh air to flow from outside to inside in the designed gap between two panes of glazing (air is driven by exhaust fan installed in the room). As it flows from the bottom of the window to the top it recovers heat that is flowing through the glass towards the outside. The fresh incoming air is heated during its passage between the two panes of glass before entering the building, through convection and conduction in the cavity. This creates a high performance window, which U-value is dependent on the environment conditions. If the window happens to receive direct solar radiation it also acts as an air solar collector, but this is not its primary operating mode.

Combination of measures

It should be noted that the presented technologies can be used together in one window in order to improve its thermal performance. Several combinations have been considered and investigated.

In order to compare performance improvements a Prototype 0, which represents the original, the unchanged box-type-window was used as a baseline. Table 3 presents a summary of performance and percentage change in relation to "original window" of each prototype/prototype mix. The improvement options influence the original windows in different ways. Prototype 3 (incorporating ultra-thin glazing) has the lowest thermal transmittance; however, installation of the insulated glazing unit may require some changes to the original window structure and is labour and cost intensive. The Air Sandwich product is easy to install in an existing window and provides some improvement in the thermal performance, however the visual appearance of the product may not be acceptable. Installing thermal shades and adhesive low-emissivity films provide some

Prototype	U-value [W/m²K]		G-value [-]	T_{vis} [-]	T_{lowest} [°C]	
	measured	calculated	calculated	calculated	measured	calculated
P0 "Original Window"	2.47	2.46	0.78	0.81	10.71	11.03
P1 "Thermal Shades"	1.92	0.99	0.58	0.54	11.48	16.6
P2 "Adhesive low-emissivity films"	2.37	2.07	0.47	0.63	10.85	12.23
P3 "Multi-layered glazing"	-	1.26	0.67	0.70	-	15.4
P4 "Air Sandwich"	1.84	1.55	0.49	0.57	12.39	14.7
P5 "Supply Air Window"	2.47*	2.46	0.78	0.81	10.71	11.03
P1 + P2	-	0.79	0.41	0.5	-	17.2
P1 + P3	-	0.79	0.49	0.46	-	17.3
P3 + P4	-	1.11	0.44	0.53	-	16.2

Table 3: Performance summary of developed prototypes

* The thermal performance of the supply air window was not simulated due to the complex nature of the system and a lack of data to develop and validate the model. The primary benefit of supply air windows is to improve air quality and recover heating energy. Literature review shows that a supply air window improves energy efficiency. A supply air window may also provide night time cooling during the summer when the outside temperature falls below the indoor air temperature. Currently running experiments will hopefully give useful data for future performance analysis.

thermal improvements but may have unacceptable visual impacts. Both technologies are relatively easy to install, and the shade may also reduce glare problems, provide privacy, and reduce solar gain. All of these strategies can be enhanced with supply air window valves which can improve thermal performance and indoor air quality if properly designed.

There is a wide range of building types with historical value in most historic urban districts, so we have investigated a number of options for window improvement which may be adapted to different types of windows. For each window and building, a specific solution should be selected which takes a balanced account of all the issues including historical value, reversibility of the change, visual appearance, thermal performance, moisture performance, indoor air quality, cost, maintenance, and durability. It is a challenge to achieve a balanced solution for improving windows in a cultural heritage building, but we need to develop acceptable solutions given that these buildings are a significant part of Europe's building stock.

Thermal and daylight simulations were conducted for several window configurations in order to find the most efficient solution for the EFFESUS case study in Budapest. Since two windows were replaced, for each we used slightly different configurations for testing purpose. The first window incorporated three layer ultra-thin glazing; the second, a two layer standard unit in inner sash. Both windows were equipped with electrically controlled shades and ventilation valves.

References:

[1] International Organization for Standardization. (2003). ISO 15099:2003 - Thermal performance of windows, doors and shading devices - Detailed calculations.
[2] International Organization for Standardization. (2006). ISO 10077-1:2006 Thermal performance of windows, doors and shutters -- Calculation of thermal transmittance -- Part 1: General, 1.
[3] International Organization for Standardization. (2003). ISO 9050:2003 Glass in building - Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors
[4] International Organization for Standardization. (1994). ISO 8990:1994 - Thermal insulation -- Determination of steady-state thermal transmission properties -- Calibrated and guarded hot box
[5] International Organization for Standardization. (2010). ISO 12567-1:2010 - Thermal performance of windows and doors -- Determination of thermal transmittance by the hot-box method -- Part 1: Complete windows and doors

Figure 18: Installation in the case study building in Budapest

3.5 TESTS IN LABORATORIES AND OUTDOOR FACILITIES

The tests of the products in laboratory and outdoor test stands served to demonstrate both their durability and their actual performance in terms of contribution to energy demand reduction in different situations.

Aerogel insulation – HotBox test on full scale stonewall mock-up

To measure the actual performance of the aerogel insulation blown into a cavity, a full scale stonewall mock-up – 1.5 m per 1.5 m and 44 cm thick – was built, and the "plaster on laths" interior finish as typically found in Scottish tenement houses was added, creating an air space of about 3-4 cm between the stone wall and finishing (see Figure 19). Similar constructions can be found, for example, in traditional Alpine farmhouses, where wooden panelling is however more common than a plaster on lath construction.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

Figure 19: Stonewall mock-up in INTENT hot box

The whole stonewall mock-up was placed in the INTENT test facility (a guarded hot box) and the U-value was measured following EN 1934 [1]. To this aim, the wall was brought into steady state conditions – "interior" side at +20°C, "outdoor" side at -10°C. Finally, the determined U-value of the stone wall with air space amounted to 1.18 W/m²K.

After blowing in aerogel with a density of 70 kg/m³, the U-value assessment was repeated under the same boundary conditions as above. The heat flux was reduced from 30 W/m² to 11.2 W/m², little more than one third of the original value. This corresponds to an average U-value of 0.41 W/m²K including also areas with wooden posts. An additional measurement in a section without wooden posts resulted in 0.38 W/m²K. Two-dimensional simulations of the heat flux and temperature distribution in the wall section accompanied the lab measurements. In Figure 20, two aspects can be clearly observed: Firstly, the reduced surface temperature of about 15°C in front of the wooden post, compared to 18°C in areas with aerogel – and the good agreement of simulated and measured temperatures. Secondly, the concentration of the major part of the temperature difference at the aerogel insulation layer – which is the visible sign of its high thermal resistance compared to the other layers.

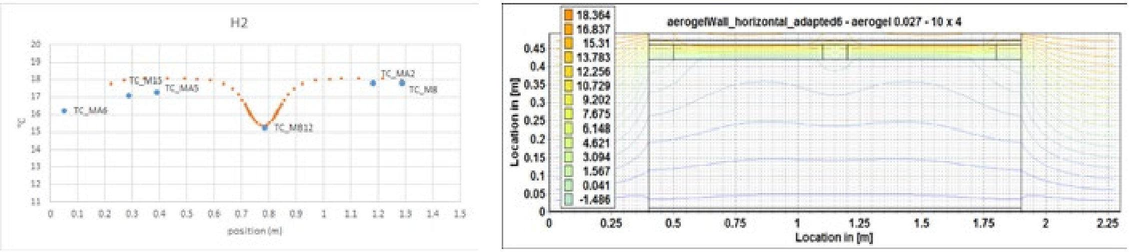


Figure 20: Temperature distribution (left) on the interior surface, measured and simulated, and (right) in the horizontal section, simulated.

EOTA wall – durability test on insulation mortar

The ISOCAL insulation mortar was tested successfully in the so-called EOTA*-wall (test according to ETAG004 [2]). This test chamber consisted of two walls, 2.1 m x 4 m, with the plaster system facing each other. One wall was built as timber frame filled with brick masonry, the other half with limestone and half with brickwork. Both walls had windows inserted in order also to test the behaviour at such construction details.

Figure 21: EOTA wall for durability test under harsh weathering conditions – before (stone masonry, left) and after plastering (timber frame, middle) as well as pull-off-test (right).

These walls were then subject to a large number of weathering cycles:

- 80 heat/rain cycles (of each six hours):
- One hour rise to 70 °C, two hours at 70 °C and 10 to 30% relative humidity, one hour rain at 15 °C, two hours drying
- After all heat/rain cycles at least 48 hours drying with closed doors.
- Five heat/cold cycles (of each 24 hours)
- One hour rise to 50 °C, seven hours at 50 °C and < 30% relative humidity, two hours fall to -20 °C, 14 hours at -20 °C
- Seven days curing and afterwards pull-off tests

Visual observation during and after the heat/rain cycles showed no cracks. The limestone and brick masonry showed only some small detachments, whereas the timber-frame/brick masonry had detachments around the wooden posts. After the finalisation, the degree of cohesion of the mortar on the wall was tested by pulling off a 5 cm x 5 cm sample. According to ETAG 004 [2], the adhesive bond strength has to be equal or higher than 0.08 N/mm^2 or the rupture shall occur in the insulation layer (cohesive rupture) if the failure resistance is less than 0.08 N/mm^2 (MPa). The measured bond strength was with about 0.04 N/mm^2 not very high. The failure was, however in all cases within the ISOCAL layer what means that the adhesion to the wall is high enough.

Additional to the normal temperature and humidity monitoring within the test chamber, plaster and supporting masonry walls were equipped with impedance and other sensors to monitor material moisture behaviour (see Figure 22) [3].

* European Organisation for Technical Assessment (EOTA) www.eota.eu

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

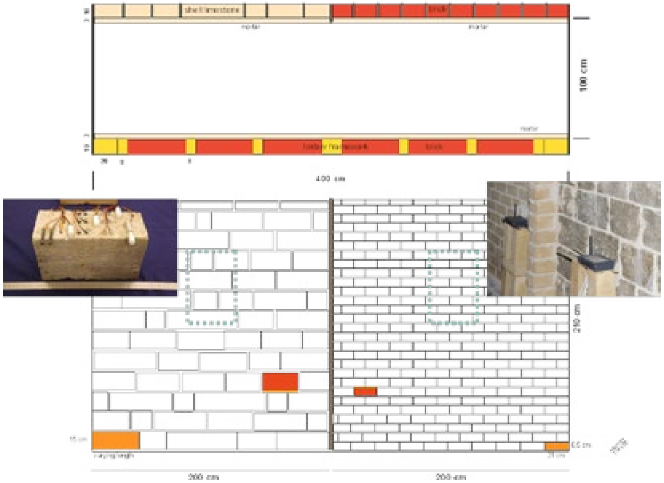


Figure 22: Sketch of the built EOTA test rig [3]. Top: Floor plan of the two walls. Bottom: Sketch of the masonry wall. Left: limestone and right: brick masonry. The two stones marked in red were equipped with sensors (left insert). Right insert: View of the two sensor nodes during operation. The doted green rectangles mark the window openings inserted. The orange stones give the dimensions of the two materials.

Results [3] show, that the moisture in the plaster itself rises nearly immediately with the first weathering cycles – the impedance in Figure 23 decreases. It takes more time for the bricks and joints to become moist. Moreover, the moisture penetrates deeper in the mortar joints than in the brick itself (Figure 23, compare measurements at 54 mm depth). Another advantage of the impedance measurement is, that it works in the full moisture range - relative humidity sensors would not give details on the over-hygroscopic moisture content [3].

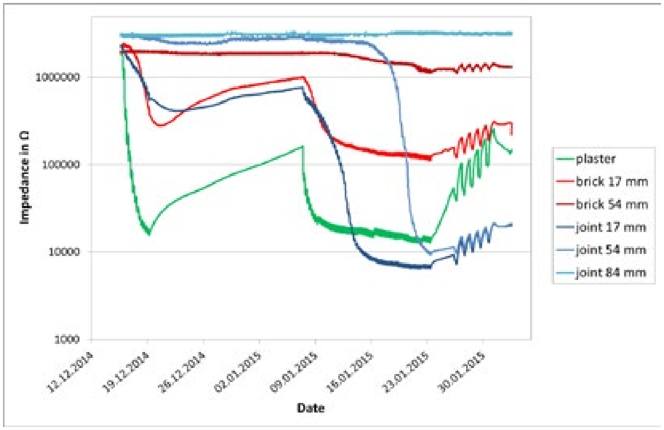


Figure 23: Impedance of all sensors at the brick wall [3].

Insulation mortar – U-value measurement under real weather conditions

The insulation mortar was tested on a 1:1 scale under real climate conditions at an outdoor test site. The recommended 3 cm of ISOCAL and 2 mm surface finishing were applied on a 1x1 m² field of the west-facing wall (the most exposed to the weather) of the half-timbered test-house. The measured humidity at the transient layer between brick and mortar – measured both in terms of moisture mass and in terms of relative humidity – shows that ISOCAL has a good drying behaviour, is effective against rain, and the absorption is not too high.
For comparison, on a second field the same wall construction (e.g. 1.3 cm internal lime plaster and 11.5 cm brick) was supplied with a lime based

standard mortar of the same thickness. While for the test field with ISOCAL the calculated U-value amounts to 1.16 W/m²K, for this reference field it is with 2.34 W/m²K nearly twice as high. Figure 24 depicts the measured heat flux in both fields: in the case of the field with ISOCAL it is by factor 2 lower – as it could be expected from the calculated U-values.

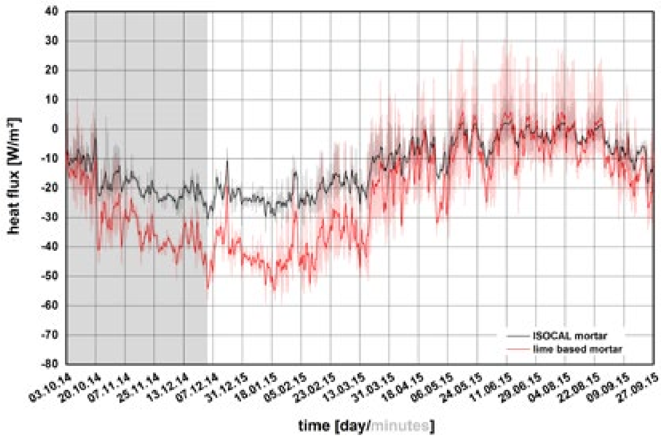


Figure 24: Measured heat flux in the test fields with ISOCAL insulation mortar and lime based standard mortar

Infrared (IR) coating on a solid brick wall – static and dynamic test

The heat flux into a wall depends on the balance of: (a) absorbed solar radiation (including the visible part of the solar spectrum and its infrared (IR) part); (b) absorbed and emitted thermal radiation; (c) convective exchange with the outside air; also on the overall thermal resistance of the wall, and the inside air temperature. That is why for the lab test on the IR coating – which should reduce the absorbed solar radiation – a full-scale mock-up wall was built and tested in the already above-mentioned INTENT hot box, this time with an artificial sun added.

Complementary simulations showed that the average heat fluxes both at interior and exterior surface of the solid wall remained the same – whether a sinus-shaped temperature and a "half-sinus" radiation is applied, or whether their average over 24 hours is considered. The test with a constant indoor temperature of 20°C, constant outdoor temperature of 25°C, and constant radiation of 330 W/m² would thus already have provided the expected result. Nevertheless, a dynamic test with outdoor temperature varying with a sinus around 25±5°C and a 12h radiation curve with 900 W/m² peak was also performed.

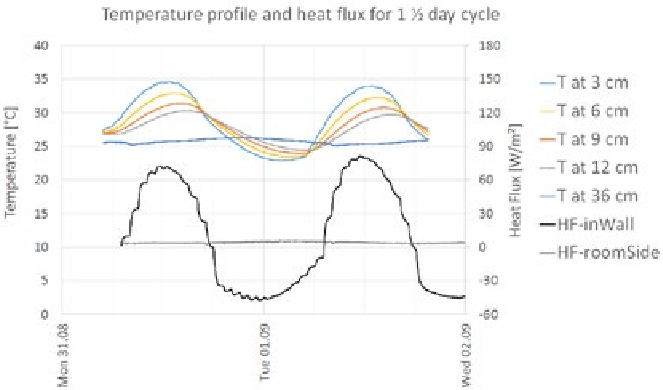


Figure 25: Results from dynamic test.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

The results of this dynamic test were especially interesting to observe: Figure 25 shows nicely the temperature profile within the wall and how the outer layer is heated up during the day and cooled down during night. The respective day and night heat flux peaks are high with respect to the average flow. The 24-hour average of the outside surface corresponds however to the rather constant heat flux at the interior surface.

IR coating performance – whole year performance in different situations

The laboratory tests of the IR coating have been completed with building simulations for different climates to determine the most promising applications.

One clear benefit is the reduction of surface temperature and, associated with that, less thermal stress at the surface:

For the Istanbul climate, for example, the average daily temperature change of the wall surface is reduced from nearly 20 Kelvin to less than 10 Kelvin – especially for the south wall, but less pronounced for the east and west walls. In terms of the high daily maxima, defined as the 10% quantile of the daily maximum temperatures, they descend from over 40°C to around 30°C.

To include an even hotter climate, also Seville climate was considered. Here, the situation is even more pronounced: the daily temperature cycles are reduced from more than 25 Kelvin to about 12 Kelvin, maxima descend from temperatures above 50°C to temperatures between 35 and 40°C.

The second expected benefit, the improved energy performance, is already more difficult to generalise. Here we have to consider the whole year performance: what is positive in summer is perhaps not desirable in winter. While in the Seville climate, the reduction of cooling demand is reduced from about 67.4 to 60 kWh/m², and the heating demand is in any case too small to matter (in the assumed example room), in Istanbul, the cooling demand reduction from 42.8 to 37.5 kWh/m² (-5.3) is counterbalanced by a heating demand increase from 13.2 to 15.8 kWh/m² (+2.6). This phenomenon does not depend on the weight of the wall – it is very similar for a medium or low weight construction if the overall resistance in terms of U-value is the same.

What matters a lot are, however, the other "summer case optimisation strategies" like reducing interior and solar loads and natural ventilation strategies: the latter can reduce the cooling demand in the Istanbul climate from about 42.8 to 19 kWh/m² (without coating), respectively 37.5 to 17 kWh/m² (with coating). A significant reduction of the loads leads also to a considerable decrease of the cooling demand to 24.2 kWh/m² (without coating), respectively 19.9 kWh/m² (with coating). These measures are thus more effective, and should therefore be considered before deciding on an IR-coating. Combinations of different measures might however be the best option in the specific case – especially where the possibilities for ventilation and load reduction are limited.

There are, however two clear "opportunity cases" for the application of IR coatings:

- Hot climates, where no heating is needed and no drawback in winter in terms of more heating balancing out the reduction in cooling has to be considered
- Warm climates, where the coating completely avoids cooling – and respective cooling systems are needed.

References:

[1] Enzi, S., Bertolin, C., Diodato, N. (2014): Snowfall time-series reconstruction in Italy in the last 300 years. In: The Holocene 24 (3): 346-356

[2] ETAG 004:2013, GUIDELINE FOR EUROPEAN TECHNICAL APPROVAL of EXTERNAL THERMAL INSULATION COMPOSITE SYSTEMS (ETICS) WITH RENDERING, Edition 2000, Amended August 2011, Amended February 2013, EOTA

[3] Frick, J.; Reichert, M.; Lehmann, F.; Stegmaier; M.; Herter, K. (2016): Moisture Monitoring during an Artificial Weathering Test of a Cultural Heritage Compatible Insulation Plaster; Proceedings of19th World Conference on Non-Destructive Testing 2016, 13 - 17 June 2016 in Munich, Germany, to be published online under Creative Commons licenses.

3.6 PERFORMANCE EVALUATION

Every innovation developed and tested at laboratory scale should be further demonstrated in practical case studies. For solutions for building envelope retrofitting in particular, the installation of the products in real-world conditions should be successfully achieved. Afterwards, the environmental performance in real-world scenarios should be proved, and the related improvement evaluated over time through monitoring activities. Finally, in the specific case of historical buildings, also the reversibility should be guaranteed, along with the criteria of compatibility.

The applicability and performance of the innovations developed within EFFESUS project have been demonstrated in four demonstration sites:

- Blown-in aerogel for use in cavities behind existing wall finishes in a traditional tenement building located in the Yorker district of Glasgow (United Kingdom);
- New thermal insulation mortars for indoor use as plaster and outdoor use as render in the Benediktbeuern Monastery (Germany);
- Radiant reflective coatings for external application in a historic building located in Kallavi Street, Beyoglu District, Istanbul (Turkey);
- Windows with improved insulation and ventilation at the Budapest University of Technology and Economics (Hungary).

This contribution is intended to illustrate the methodology followed in the second step of the on-site demonstration in the above-mentioned case studies, where the performance of the new products has been assessed in terms of improvements to indoor environmental quality (thermal, visual, acoustic comfort and/or air quality in function of the technology to be validated) and reduction of energy consumption. This methodology could be replicated and adapted to the evaluation of other energy-efficient solutions suitable for application to historic buildings.

First of all, a comparison between the conditions with and without the innovation is required in order to understand qualitatively and quantitatively the improvements. This comparison can be carried out in two ways:

- By monitoring the parameters simultaneously in a test area and in an equivalent unmodified reference area, which assures the same boundary conditions, the same physical characteristics, and enabling the analysis of data in the same period of time;
- By monitoring the parameters in the same area but before and after the intervention. In this case, it is necessary to compare the data from the two different periods with similarly outdoor weather conditions.

An appropriate monitoring period is about 12 months in order to cover the different seasons along the year.

All the variables that can influence the behaviour of the materials constituting the building envelope have to be taken into account and carefully analysed, for example: climate, location in the urban settlement, orientation, direct impact of solar radiation, shape of the building ensemble, typology and constructional materials of the walls, thickness of the walls, percentage of area covered by windows, and type of windows.

Afterwards, the scope of the evaluation has to be defined in function of the technology under question; that is, if it affects the thermal, visual, acoustic comfort of people, the indoor air quality, or a combination of these items. Based on this, the parameters to be monitored have to be selected and the equipment and installation set-up planned accordingly.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

As mentioned above, the performance of innovations can be carried out in terms of improvements to indoor comfort and reduction of energy consumption. On one side, energy consumption could be easily monitored by measuring the electric input power, while energy saving could be calculated from the associated costs. On the other side, the evaluation of people comfort deserves a separate discussion.

The thermal comfort assessment includes some objectively and measurable performance indicators, as well as human thermal sensations related to the thermal balance of the body, which are influenced by physical activity and clothing as well as the environmental parameters. These aspects are summed up in the Predicted Mean Vote (PMV) indicator, which integrates four environmental parameters and two personal parameters (metabolic rate and clothing insulation). ISO 7730 [1] explains how to calculate PMV according to the Fanger equation; it also prescribes a maximum Percentage of Persons Dissatisfied (PPD) for the human body as a whole, and for local thermal discomfort conditions due to draught, vertical temperature gradient, radiant asymmetry, warm/cool floors.
For the determination of PMV and PDD, the following parameters have to be measured: air temperature, relative humidity, surface temperature of walls, air velocity, and mean radiant temperature or operative temperature (measured by a globe-thermometer).

Acoustic comfort means having the right level and quality of noise to use the space as intended. How humans perceive sounds and loudness is a subjective measure. However, it is possible to create a comfortable environment by controlling objective measures like decibel levels or indoor ambient noise levels in unoccupied spaces. Generally, upper limits for the indoor ambient noise levels for each type of unoccupied space are defined [2].
Such measures can be carried out by means of a sound generator (amplifier and loud speakers) placed outside the window, and a receiver (sensitive microphone) placed inside the room to measure the noise levels from external sources.

The visual performance defines whether the lighting solution in a room is suitable for the performed tasks, therefore the degree of comfort depends on the type and duration of the activities.
The visual comfort is mainly determined by the illuminance level, defined as the amount of light falling on a given surface area, and the illuminance uniformity (the illuminance of the surrounding areas is connected to the illuminance of the task area, otherwise visual stress or discomfort can arise). BS EN 12464 [3] presents the requirements for lighting in the task and surroundings areas of most indoor workplaces, in terms of quantity and quality of light.

The quality of indoor air is affected by all components of the environment, namely temperature and humidity level, ventilation rate, CO_2 concentration, particulate matter, gaseous pollutants, microbial contaminants, etc. Chemicals are emitted into the air from both natural and anthropogenic sources: this results in a natural background concentration that varies according to local sources and/or specific weather conditions. Even where dealing with indoor air quality, a measurement of the outdoor pollutants is suggested in order to better identify the source and type of these contaminants.

Next to the common measurements of temperature, relative humidity and CO_2 concentration, it is important to obtain an idea of the indoor amount of Volatile Organic Compounds (VOCs). They include a variety of chemicals, some of which may have short- and long-term adverse health effects. Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors, and they are emitted by a wide array of products (for example paints and lacquers, paint strippers, cleaning supplies, building materials and furnishings, glues and adhesives). On the contrary, particulate matter mainly has external sources (from vehicles, operations that involve the burning of fuels, reaction of gases or droplets in the atmosphere from sources such as power plants), whilst indoor sources of fine particles are tobacco smoke, cooking, burning candles or oil lamps, and operating fireplaces and fuel-burning space heaters (such as kerosene heaters).

The simplest way to have basic information about the concentration of VOCs inside a room is to use a chemical detection system, which does not separate the mixture into its individual components. This principle is used in direct-reading instruments, which provide the measurement of the total concentration of volatile organic compounds (TVOC). Generally, a low TVOC usually indicates that there is no VOC problem (unless, the TVOC value is due to only a small number of compounds); however, a high TVOC values may result from a high level of one single compound, or a large collection of low compound levels that form a chemical mixture, or it may be anything in between.

Guideline values of concentration thresholds for a selection of pollutants have been published by the World Health Organization (WHO) [4,5].

So far as microbial contaminants are concerned, indicators of dampness and microbial growth include the presence of condensation on surfaces or in structures, visible mould, perceived mould odour, and a history of water damage, leakage or penetration.

As the relationships between dampness, microbial exposure and health effects cannot be quantified precisely, no quantitative, health-based guideline values or thresholds can be recommended for acceptable levels of contamination by microorganisms. Instead, it is recommended that dampness and mould-related problems should be prevented through a proper control of temperature and management of ventilation.

References:

[1] ISO 7730-2005, Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. International Standards Organization, Geneva, 2005.

[2] CEN/TC 156, prEN 15251, Indoor environmental input parameters for design and assessment of energy performance of buildings-addressing indoor air quality, thermal environment, lighting and acoustics. 2006-07-31.

[3] BS EN 12464-1:2003, Light and lighting — Lighting of work places. Part 1: Indoor work places. 2003.

[4] World Health Organization (WHO), Indoor Air Quality Guidelines for Europe. Second Edition, WHO Regional Publications, European Series, No. 91, Regional Office for Europe Copenhagen, 2000.

[5] World Health Organization (WHO), WHO Guidelines for Indoor Air Quality – Selected pollutants, Regional Office for Europe Copenhagen, 2010.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

3.7 APPLICATION OF EFFESUS INNOVATIONS FROM A RESTORER'S PERSPECTIVE

This section details the main features of the products developed and validated in EFFESUS and the application process recommended.

Aerogel insulation

The aerogel insulation named Spacefill has been successfully validated through the EFFESUS project. Trials have proven success in terms of installation and energy performance.

The application guide for users is as follows:

1. Installation must be carried out by an experienced cavity wall insulation installer using existing installation techniques.
2. It must be ensured that there is a suitable cavity for filling, and that the wall finish is in good enough condition to accept a pumped in insulation: e.g. no visible cracks, the lath & plaster is secure with minimal movement when pressed.
3. A bore hole is cut out in each wall panel to enable the insulation to be infilled.
4. Check that the cavity can be sealed at the top and bottom (to prevent Spacefill seaping out). This would be typically done when using any traditional cavity fill insulation.
5. It is advised to wear gloves and a dust mask during the installation process.
6. The 5 mm cubes are fed into the machine which can then be blown into the cavity as insulation.
7. A Test Box to confirm the density of the material to be blown in should be done prior to the installation. This should be carried out outdoors.
8. A small amount of dust is generated during the installation, however this is harmless.
9. It is important to ensure the entire cavity is filled and there are no blockages preventing the insulation from filling the entire cavity.
10. The borehole plugs can then be replaced and sealed. The wall is then ready for decoration.

Insulation Mortar

ISOCAL is an excellent thermal insulating mortar which can be used for both indoor and outdoor application. It can be applied on mineral substrates such as natural stone, brick, ceramic block, old intact mineral render/plaster and concrete. It can have hand or spray application.
ISOCAL is a lightweight material (up to 3 cm layer thickness in one application) which is easy to employ. Only one bag system, ready to be used (water to add), and an entire process with primary layer and finishing layer to employ, but at the same time it can be used with

other finishing layers such as clay. Another benefit of ISOCAL is the same indoor comfort if the room is heated at a low temperature (for example at 14°C) in comparison to a standard heated room (~20°C).

Nevertheless, when using ISOCAL some limitations must be considered. On the one hand, some finishing products cannot be used: for example, cement based coatings. Additionally, special attention must be paid to wood structures, especially in case of new wood since there is the possibility of shrinkage and consequently loss of insulation.

At the same time, in order to avoid recycling problems, the cleaning of tools must be done in specific boxes to separate polystyrene and water. The same problem will arise in case of removing ISOCAL.
The following installation process must be pursued:

1. The wall must be cleaned of any incompatible materials particularly cement.
2. It must be rough enough to allow the ISOCAL to adhere.
3. It is important that the temperature must be as the datasheet expected it.
4. If the wall is not flat, then several layers will be applied.
5. In situations of high humidity rate, ISOCAL is not an appropriate solution

Radiant reflective coating

The radiant (IR) reflective coating has shown good thermal performance, but it has some problems when applied on Cultural Heritage buildings since it must be a transparent and reversible solution.
In the case of the installation of the radiant reflective coating, the following instructions/recommendations must be followed:

1. The application of the coating is recommended to be carried out by experienced personnel using conventional techniques (brush, roll, spraying, etc.).
2. The coating application procedure is as follows:
   - Application of first Paraloid layer and 24 hour drying.
   - Application of second Paraloid layer and 24 hour drying.
   - Application of first coating layer and 24 hour drying.
   - Application of second coating layer.
   - Rest for another seven days.
3. It must be ensured that the surface is clean and dry before the coating application.
4. It is advised to wear gloves, a dust mask and protective clothes during the application process.
5. No coating application shall be done if the relative humidity is more than 85 % and when the surface temperature is less than 0°C.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

4 DECISION SUPPORT FOR ENERGY INTERVENTIONS IN HISTORIC URBAN DISTRICTS

4. DECISION SUPPORT FOR ENERGY INTERVENTIONS IN HISTORIC URBAN DISTRICTS

A major outcome of the EFFESUS project is the Decision Support System (DSS), an ecosystem of tools and methodologies to support evidence based diagnosis and decision-making, to identify and prioritise retrofit measures to improve the energy performance of historic districts. The project has developed a data model, a solutions repository, two software tools and a methodology that support the implementation of different processes within the framework. The multiscale data model and the repository have been explained in the previous chapters. In order to facilitate the implementation of a modelling strategy, a categorisation tool has been created. This web application uses information from the multiscale data model to perform a categorisation of the building stock and support the selection of representative buildings. A decision-making methodology has been developed and implemented in an expert system that guides the user in the selection of the best strategies for a historic district.

Main target groups of the Decision Support System developed by EFFESUS are municipalities and urban managers responsible for improving the sustainability of historic districts and guiding the stakeholders in this process, as they usually coordinate the first phase of the retrofitting process on which EFFESUS is focused. As for the use of the DSS, some features will require a degree of expertise in relation to cultural heritage assessment and energy efficiency; the "direct user" of the tool could be the technical staff of these organisations, or architectural and engineering firms, possibly as subcontractors. Other stakeholders interested in the tool could be grant managers (energy agencies, European Commission etc.), owners, investors, building solution providers, building users, local/regional authorities for building and heritage conservation etc.

Different levels of decision-making have been established depending on the information availability and the stage of the process [1] in order to maximise the application possibilities. The strategies are selected by using a multiscale heritage significance impact assessment method to estimate the applicability of the solutions, in combination with multi-criteria methods, to rank the strategies according to user preferences. Eventually the estimation of impact indicators at district level, to calculate energy demand and carbon emissions reduction, thermal comfort and indoor air quality improvement as well as the economic feasibility of the proposed solutions, are conducted.

References:

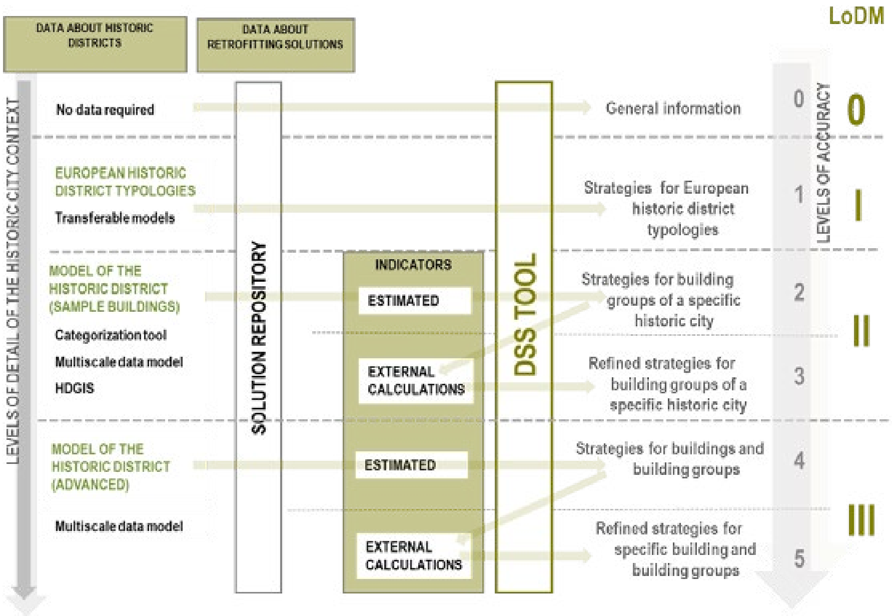
[1] A. Egusquiza, I. Prieto, and A. Romero, "Multiscale information management for sustainable districts rehabilitation : EFFESUS and FASUDIR projects," in eWork and eBusiness in Architecture, Engineering and Construction ECPPM 2014, 2014, pp. 303–308.

4.1 FUNCTIONALITY

Levels of Decision Making

Four Levels of Decision Making (LoDM) have been defined, relating to four different levels of information availability:

- No information: the user could just access generic information (Level 0)
- Low level: the information will be provided by the user through questions defined by the transferable models, based on the European building stock categorisation. No data model will be used (Level I).
- Medium level: The multiscale data model described in Chapter 1.2 will be used at this level, but only with a low level of detail. This information will be sufficient for the categorisation tool (described in this chapter), in order to identify building typologies within the historic district and "sample buildings" that represent those typologies. A more complete information regarding these buildings in the data model will allow the user of the Decision Support System (DSS) to obtain results that could be extrapolated to the entire category and consequently to the whole district according to their level of representation (Level II).
- High level: when the data model has complete information regarding a high percentage of the buildings of the district (Level III).



The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

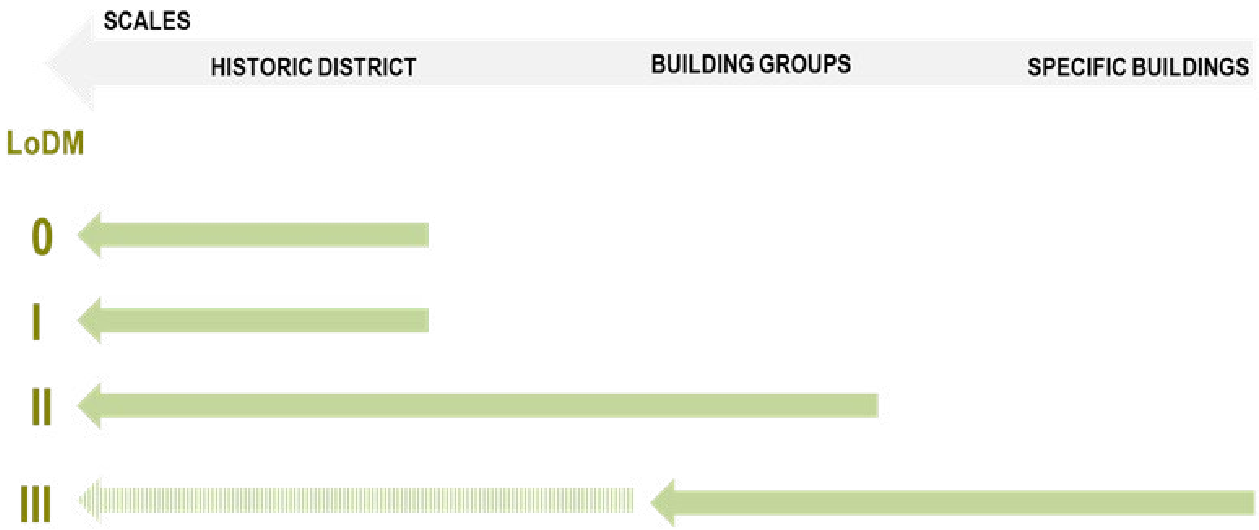


Figure 26: Scales of levels of decision-making

Criteria and constraints for decision-making

The first step in any decision-making is to choose which factors are important. EFFESUS considers the following factors as important in the process:

- Improvements of habitability and indoor environment quality
- Energy savings
- Economic, technical and legislative feasibility
- Compatibility with the architectural, historical, constructional and sustainable characteristics of the historic district

Three of these indicators have been considered as evaluating criteria for selecting the best solutions and technologies: habitability and indoor environment, energy savings, and economic feasibility. The respect for heritage significance and the observance of conservation principles are key for the project objectives, so they have been considered as constraints for the decision-making process.

A location-specific heritage significance method has been developed. The assessment method is based on a 0-4 scale to evaluate the vulnerability of the buildings and the potential impact of the retrofit measures. This is done by, firstly, identifying the heritage significance of building and urban elements, such as walls, roofs and urban spaces, and secondly, defining the various impacts of retrofit measures on the elements with regard to heritage significance, technical compatibility, and other factors. Finally, this information can be matched for specific elements to establish the suitability of a specific retrofit measure for that particular element.

Overall methodology

The overall methodology has been structured based on six stages:

1. **Modelling:** where the model of the city is generated
2. **Current state definition:** where the diagnosis of the district is carried out
3. **Target definition:** where the objectives and preferences of the user are defined
4. **Strategy definition:** where the most suitable energy retrofitting strategies are compared and selected
5. **Implementation:** where the strategies are deployed
6. **Monitoring:** where the success of the strategies in practice is evaluated

The generation of the city model will allow the testing of different scenarios for the assessment of the strategies. The modelling will be different according to the levels of available information. Using the model and some of the indicators, the current state of the historic district can be identified. This would also include the constraints regarding the historic value and the compatibility. The indicators and the constraints that will be used will depend on decision-making and accuracy levels.

The definition of the objectives and the preferences of the users at urban level will be the first step in the decision-making process. The definition of the strategy is the "core" step of the methodology. The steps will be as follows:

- Compiling a list of solutions filtered according to the defined constraints
- Ranking of technologies according to the criteria (indoor environment, energy performance and economic feasibility) and the weighting system that have been selected by the user.
- Definition of the rehabilitation strategy at urban level. This Strategy will be translated to the executive scale (the building scale), to set the objectives and the rehabilitation strategy at this level.

The whole methodology has to be able to articulate the structuring of all new information and feedback generated during the process. All the phases of the intervention at building level (the diagnosis, the design of the intervention and its implementation) will generate new information about specific buildings that will complete the multiscale data model of the historic district and enable more accurate decision-making. The indicators at urban level will allow monitoring the real improvement of the strategies and consequently the whole process will be refined.

EFFESUS Categorisation tool

Based on the method described above, EFFESUS has developed a categorisation tool, a software application that will provide the user with an easy and intuitive way for the identification of building typologies of a specific historic district. The tool is based on information from the district data model and its outputs; a small number of archetypal or sample buildings are used as input for the DSS. Thereby, the DSS receives sufficient input of location-specific data to assess the impact of retrofit measures at the specific historic district. However, to perform such assessments, the DSS also requires information on the measures to consider and their impacts. This information is stored in the technical repository.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

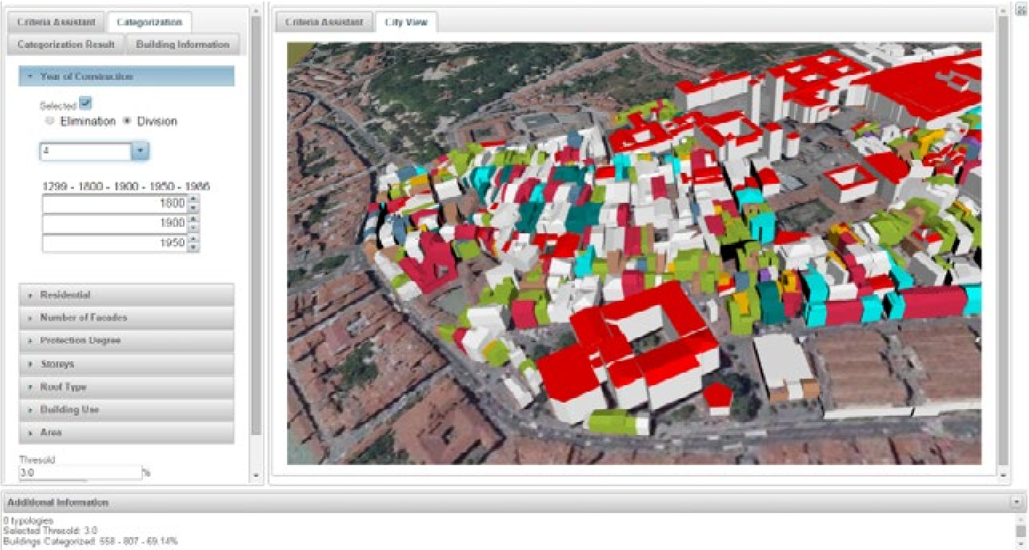


Figure 27: Screenshot of the categorisation tool

Expert system

To support professionals in the strategic decision-making processes for retrofitting historic urban districts, the expert system developed in EFFESUS requires two types of data inputs: location-specific data about the district, and technical data about available retrofit measures and associated assessment indicators. The data of retrofit measures are not location-specific and are stored in the technical repository. As the availability, completeness and quality of district data can vary significantly, the DSS has been developed so that it can perform assessments at four different detail levels, as explained above. The district data inputs will obviously have a significant impact on the outputs the DSS can deliver.

Where hardly any suitable district data is available, the DSS will base its assessment solely on the geographic location of the districts (Level 0 assessments). In this case, the outputs of the DSS will be basic information about building retrofits suitable for the climatic region in which the district is located. Where the software user is able to provide at least some minimum information about the district, a level 1 assessment can be performed, by assigning a district type to the district and comparing it against standard typologies saved in a transferable model together with suitable retrofit guidance. In this case, the DSS output is based on the district's climatic region and its typology. The DSS will guide its users through a set of questions, selecting the parameters which are required to allow the identification of the district type. For both level 0 and level 1 assessments, no district data model is required.

Only where sufficient data is available to generate a data model, the more advanced assessments of detail levels 2 and 3 can be performed by the DSS. Where datasets are of little completeness, a level 2 assessment will be used, based on an analysis of the building stock using the Building Stock Categorisation Tool. Thereby, the district will be reduced to a suitable small number of typical buildings, for which sufficient data is either already available or can be obtained reasonably easy. The DSS assessment will base its assessment on these typical buildings and extrapolate its results to the whole district. Only where complete or near complete district datasets are available, a level 3 assessment be conducted. In this assessment case, the DSS uses data straight from the multiscale spatial district data model. These assessments will be the most detailed and reliable ones, but will also be the most resource consuming, particularly with regard to the identification and preparation of the district input data.

For level 2 and 3 assessments, the DSS will analyse the impact of the various retrofit measures catalogued in the Technical Repository (see chapter 2.1 of this booklet) as if they were to be installed in the district. The impacts will be assessed using the indicators listed in the repository, with regard to economic return, energy consumption (embodied and operational), indoor environment, heritage significance, and technical compatibility. The latter two assessment aspects are implemented in the DSS as constraints to filter out retrofit measures which are considered as unsuitable, regardless of the outcome of the other assessment aspects. The assessment process will identify, for each assessment aspect, those retrofit measures which are the most suitable for a specific district. In a final step, the DSS will combine the identified measures into recommended packages of retrofit measures, for further investigation by professionals to confirm their suitability in specific building cases.

To make the DSS more interactive, users can set strategic priorities, for example by identifying and balancing capital expenditure against anticipated savings in energy or carbon emissions, or by identifying improvements of the indoor environment.
To sum up, the inputs from the data model and the technical repository are used by the DSS to produce.

- A current state regarding energy demand and carbon emissions
- A list of possible solutions classified by their applicability
- A priority list of packages of retrofit measures which are likely to be suitable in the context of a specific historic district

References:

[1] A. Egusquiza, I. Prieto, and A. Romero, "Multiscale information management for sustainable districts rehabilitation : EFFESUS and FASUDIR projects," in eWork and eBusiness in Architecture, Engineering and Construction ECPPM 2014, 2014, pp. 303–308.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

4.2 USER INTERFACE

The EFFESUS Decision Support System (DSS) is an innovative system for the assessment of energy-related interventions in built cultural heritage at building and district level. It supports users to select and prioritise energy interventions with full respect to the historical significance of the buildings. This section provides a brief description of the system's user interface, focused on presenting the outcomes of the main functionalities of the DSS.

Homepage

The homepage of the DSS provides general information about the system to urban planners or other stakeholders. Users can read further information about the EFFESUS project (innovations, outcomes), the DSS, European national policies regarding energy and cultural heritage, best practices, etc., by choosing one of the options that feature in the "General Information" tab at the main menu bar. Users can register or login to the Decision Support System by the "Account" menu. It is important to note that only registered users can create or edit their own projects. Users can search for a specific topic by using the "Search" section on the top main menu bar and typing a term into the search box. The system will then search for pages containing that term anywhere in the page name or page content. When the search is completed, a list of links will appear.

Projects

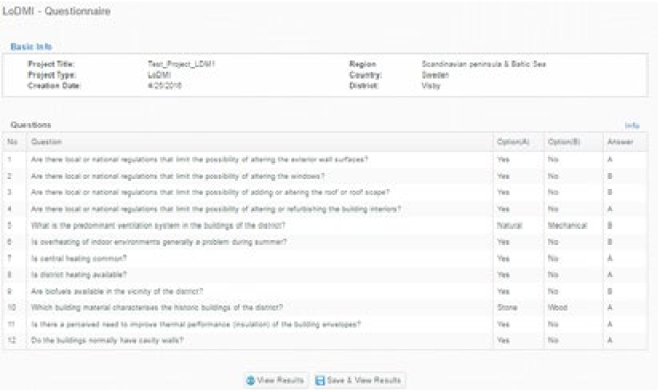
On the "Projects" tab on the top main menu bar, registered users are able to manage their existing projects or create new ones.

Utilising the user-friendly interface, users can exploit the numerous functionalities that the system offers to manage their projects. Specifically, the user can create, open, edit and change the settings of a project and delete it. Depending on the type of the project (Level 1 or Level 2) which the user attempts to open, the forms Level 1 (LoDMI – Questionnaire) and Level 2 (LoDMII - All Buildings) are displayed correspondingly.

The collaboration tool enables a user to upload and store significant documents and to share it with other users. Additionally, users can establish links to communicate with other users via a wide range of means (email, telephone, teleconference, appointment, etc.). An informative panel ("Logs") provides details about the current project tasks, such as the selection of buildings, the evaluation of solutions and other ones.

Level 1 Project

In the "Level 1 (LoDMI – Questionnaire" form (see Figure 28) the user can see information about the project and give answers to twelve predefined questions. The DSS will need to take into account the user's input and, using a data-driven decision approach, query the solutions repository and provide the user with the results. The system guides the user into the process providing the required information, which allows identifying the main characteristics of the historic district. Level 1 projects provide the users the possibility to create projects in order to obtain solutions and recommendations for the selected historic districts based on information about the main characteristics of the historic district. On the slide up-down buttons in the "Level 1 (LoDMI – Results)" form, the results for the climate analysis, the strategies, the best practices and the types of solutions appear.



LoDMI - Questionnaire

Basic Info

Project Title:	Test_Project_LDMI	Region:	Scandinavian peninsula & Baltic Sea
Project Type:	LoDMI	Country:	Sweden
Creation Date:	4/25/2016	District:	Visby

Questions — Info

No	Question	Option(A)	Option(B)	Answer
1	Are there local or national regulations that limit the possibility of altering the exterior wall surfaces?	Yes	No	A
2	Are there local or national regulations that limit the possibility of altering the windows?	Yes	No	B
3	Are there local or national regulations that limit the possibility of adding or altering the roof or roof scape?	Yes	No	B
4	Are there local or national regulations that limit the possibility of altering or refurbishing the building interiors?	Yes	No	A
5	What is the predominant ventilation system in the buildings of the district?	Natural	Mechanical	B
6	Is overheating of indoor environments generally a problem during summer?	Yes	No	B
7	Is central heating common?	Yes	No	A
8	Is district heating available?	Yes	No	A
9	Are biofuels available in the vicinity of the district?	Yes	No	B
10	Which building material characterises the historic buildings of the district?	Stone	Wood	A
11	Is there a perceived need to improve thermal performance (insulation) of the building envelopes?	Yes	No	A
12	Do the buildings normally have cavity walls?	Yes	No	A

View Results | Save & View Results

Figure 28: Level 1 (LoDMI – Questionnaire) form

Level 2 Project

Level 2 (LoDMII) projects consist of three major functionalities. These are:

- **Modelling:** the user is working with the Categorisation Tool to select "sample buildings", which will represent the different "groups" of buildings of the historic urban district
- **Current State:** represents the conditions of the "sample buildings".
- **Decision Making:** guides the user to define the best strategies for selecting and prioritising energy efficiency interventions in the historic district.

Modelling

At this level, a "Categorisation Tool" is utilised to define the representative buildings of the historic district by identifying building typologies.

The user can interact with the tool, editing parameters and thresholds for categorisation as well as editing properties of representative buildings. The process for the categorisation consists of five main steps:

1) Statistical overview of the parameters (see Figure 29)
2) Selection of the parameters and value ranges
3) Generation of the typologies and selection of the representative typologies (see Figure 30)
4) Selecting sample buildings
5) Completion of the information regarding the selected sample building.

The Categorisation tool is linked to the DSS, and the result of this step will allow the identification of building typologies within the historic urban district, and "sample buildings" that represent those typologies ("Load All Buildings").

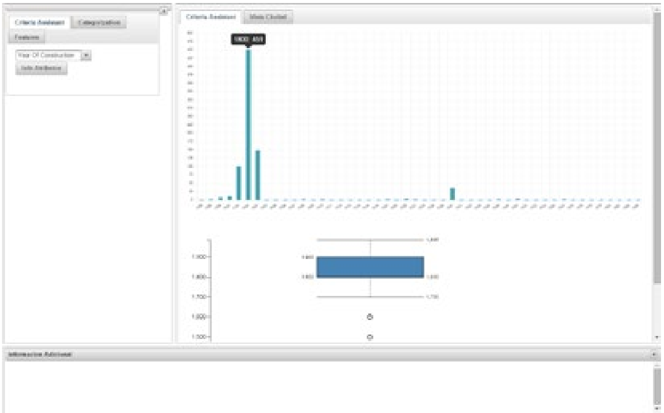


Figure 29: Statistical overview of categorisation parameters in the Categorisation Tool

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

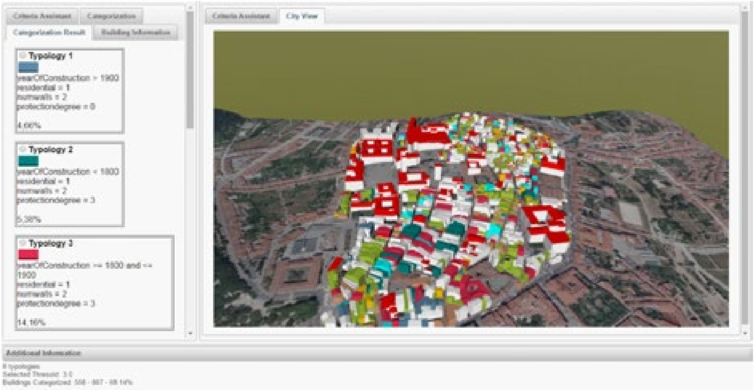


Figure 30: Selection of representative typologies in the Categorisation tool

The next step is to complete the data model with detailed information for these sample buildings. That allows the DSS to obtain results that could be extrapolated to all the categories and consequently to the whole district according to their representativeness, and could establish the impacts of the selected retrofit strategies. To accomplish this process, users have to choose one “sample building” at a time and click on “Open selected building” to proceed to the Building Evaluation page.

Building evaluation

This phase comprises six steps which describe the current state of the sample buildings as well as the decision-making process.

Step 1: Building / District Information

In this step, basic information about the project, the region and the district are entered as well as details about the basic attributes of the current building such as:

- Number of storeys
- Ground floor area (m^2)
- Year of construction
- Principal use
- Percentage of openings: presents the opening area (m2) of the building divided by the total wall and roof area (m2) of the building

Additionally, in the panel “Energy Efficiency Indicators”, information about the thermal energy use per year and floor area, as well as CO_2 emissions, are presented (see Figure 31).

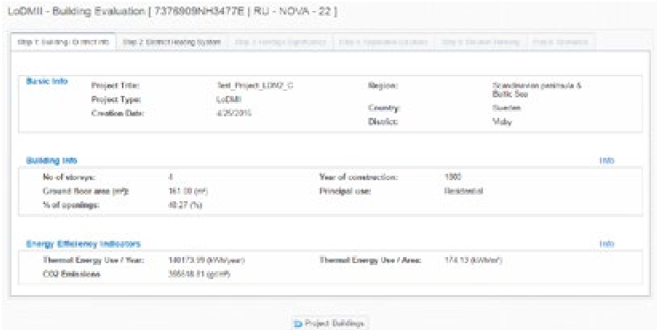


Figure 31: Building / District Information

Step 2: District Heating System

In the next panel, "District Heating System", the DSS displays information about the district heating system (see Figure 32). The heat density of a specific area is the first indicator which is used to get an overall understanding of the economic feasibility of a district heating installation. The heat energy demand of all dwellings (DW) and commercial buildings (CB) are put in relation to the planned supply area. If the heat demand and heat density is sufficiently high for a centralised heating system the decision process will be used. The decision process depends on further local parameters such as renewable energies potentials, biomass or waste potential, possibilities for a distribution grid and existing space for power plants, the connection rate and development velocity. The DSS takes under consideration all these information and estimates the decentralised or centralised energy solution.

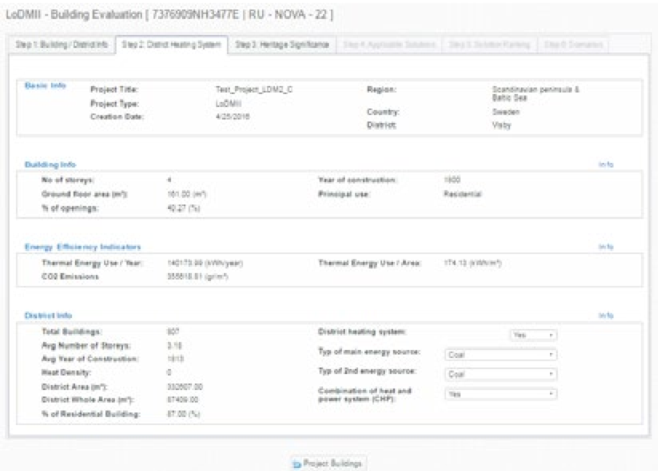


Figure 32: District Heating System

Step 3: Heritage Significance

In the panel "Heritage Significance Table" the heritage significance indicator for every part (walls, roof, etc) of the sample building is displayed. The scale that measures the degree of heritage significance of these elements is:

0= Neutral or negative significance
1= Minor significance
2= Major significance
3= Outstanding significance
4= Exceptionally outstanding significance

In the panel "Heritage Significance Chart", the pie charts of heritage significance are displayed, each one of them corresponds to each one of the significance types (visual, spatial and physical). The distribution categories are:

3 or higher = Outstanding or exceptionally significance
1 or 2 = Minor or major significance
0 = Neutral or negative significance

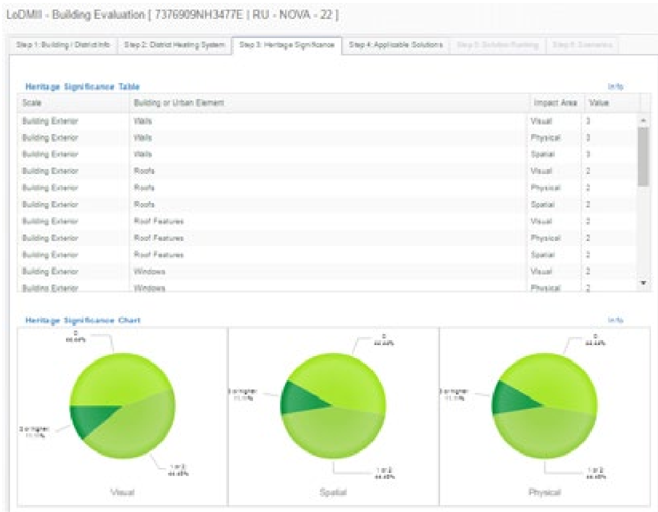


Figure 33: Heritage Significance Table and Chart

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

Step 4: Applicable Solution

The "Applicable Solution" panel presents a list of solutions which are ranked and grouped in the following categories:

- Acceptable
- Likely to be acceptable
- Potentially acceptable
- Not acceptable

The assessment is done by comparing the impact of retrofit measures with the heritage significance assessment, and is based on the following table:

		Impact definition				
		0= No impact	1=No significant impact on heritage significance	2=Minor impact on heritage significance	3=Major impact on heritage significance	4= Outstanding impact on heritage significance
Heritage significance	0= Neutral or negative	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
	1= Minor significance	Acceptable	Acceptable	Likely to be acceptable	Likely to be acceptable	Potentially acceptable
	2= Major significance	Acceptable	Likely to be acceptable	Potentially acceptable	Potentially acceptable	Not acceptable
	3= Outstanding significance	Acceptable	Likely to be acceptable	Potentially acceptable	Not acceptable	Not acceptable
	4= Exceptionally outstanding significance	Likely to be acceptable	Potentially acceptable	Not acceptable	Not acceptable	Not acceptable

Table 4: Heritage significance assessment

In Figure 34 a list of applicable solutions estimated by the DSS, taking into account the sample building's overall heritage significance value and the impact of each repository solution, appears. The user can remove the unwanted applicable solutions by clicking on the "Delete" button.

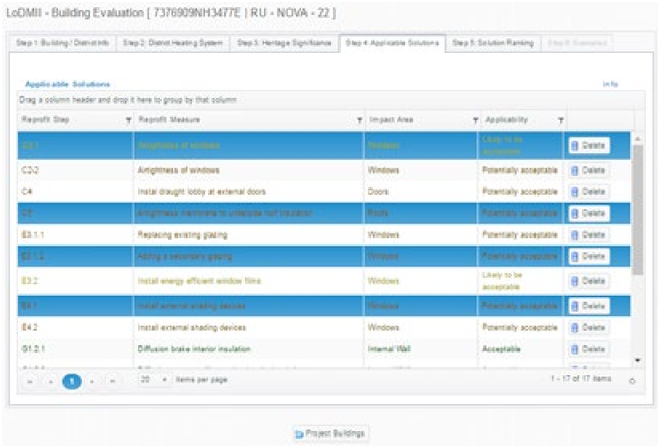


Figure 34: Table of Applicable Solutions

Step 5: Solution Ranking

To rank the applicable solutions, users can choose one of the two available decision-making methods, namely Analytic Hierarchy Process (AHP) and Simple Multi-Attribute Rating Technique SMART as shown in figure 35. Five different criteria will be considered at this stage:

- Thermal Comfort (TC)
- Indoor Air Quality (IAQ)
- Energy Saving (ES)
- Cost
- Low Impact Solutions (LIS)

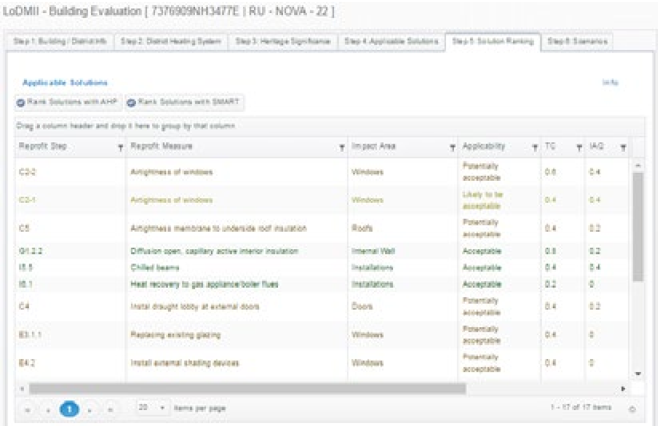


Figure 35: Ranking Applicable Solutions

The user can evaluate in pairs the above criteria by using the following scale:

- Extremely preferred=9
- Very strongly preferred=7
- Strongly preferred=5
- Moderately preferred=3
- Equally preferred=1

The assigned weights from the paired comparison of the criteria are used by the AHP to find the best single retrofit solution. Finally, the DSS updates the table of applicable solutions with the ranking results.

On the other hand, using the SMART method, user estimates the relative importance of each criterion giving a value to the corresponding slider. Then weightings for each criterion are calculated and the selected solutions are ranked. The DSS updates the applicable solutions table with the ranking results.

In the panel **"Ranked Solutions Charts"**, the DSS displays charts presenting the ranking outcomes. The top input bar of the chart is used to select the indicators the user wants to be displayed.

Step 6: Scenarios

Users can create scenarios (packages) of solutions in order to assess different strategies manually, or ask the system to select the best solutions automatically (Multi-Objective Programming - MOP). To generate scenarios manually, the following steps should be undertaken (see Figure 36):

- Choose the solutions which are going to be included in the scenario.
- Name the new scenario.
- Click on the "Create Scenario" button.

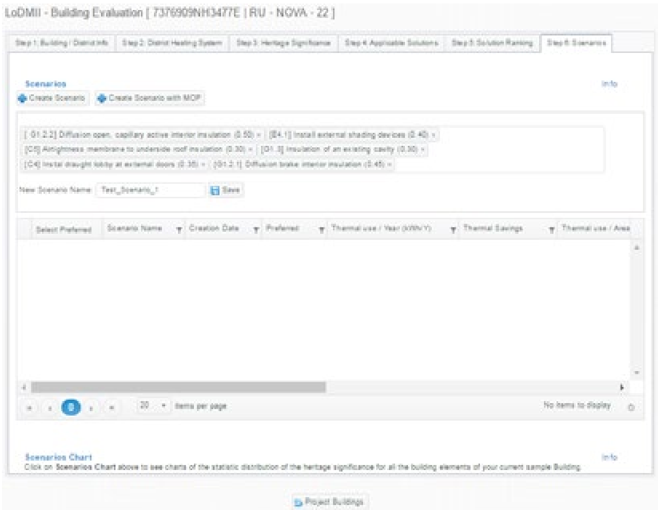


Figure 36: Create/Manage Scenarios

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

Each created scenario is added to the corresponding "Scenarios" panel (see Figure 37). The scenarios are assessed in terms of the energy indicators and the impact on the indicators Thermal Comfort (TC), Indoor Air Quality (IAQ), Energy Saving (ES), Cost and Low Impact Solutions (LIS). In the panel "Scenarios Chart" each of these indicators is plotted (see Figure 37). Also a visual comparison between different scenarios is provided.

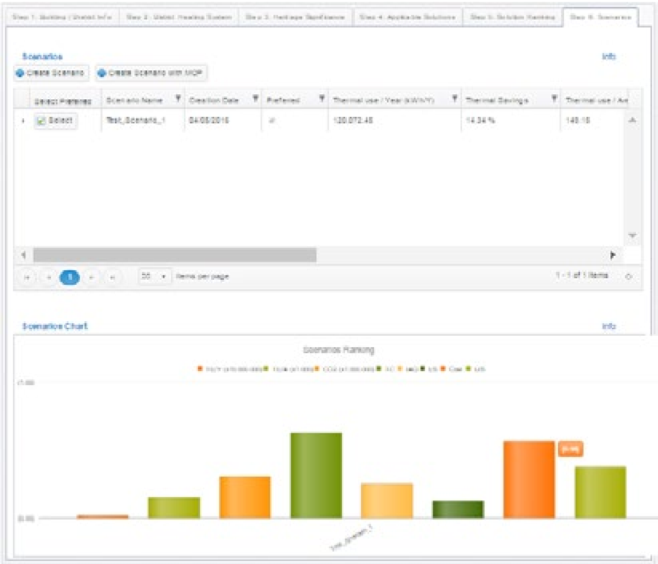


Figure 37: List of Scenarios and scenarios bar chart

To let the DSS automatically create an optimal scenario of solutions using MOP, the following steps should be undertaken:

1. Click on the **"Create Scenario with MOP"** button.
2. In the pop-up window, choose a threshold for cost impact and give the name for the scenario.
3. Click on the "Find Optimal Combination of Solutions and Generate Package" button. The DSS will then execute the MOP algorithm and add the new scenario to the scenario list.

In the panel **"Scenarios Chart"**, the visualisation of the impact on the indicators for each scenario is plotted on a bar chart.

4.3 VALIDATION OF THE EFFESUS DECISION SUPPORT SYSTEM

As its main output, the EFFESUS project has developed a software tool to aid the strategic decision-making process of retrofitting historic urban districts to improve their energy performance [1]. This Decision Support System (DSS) is a web-based tool for professionals to analyse and prioritise retrofit measures suitable in a historic context [2,3]. The tool requires as input two data sets: location-specific data about the urban district to be interrogated and a catalogue of generic retrofit measures. The latter was developed by EFFESUS in the form of a Technical Repository [4]. The location-specific data should ideally include information about the buildings in the historic district (including building age, construction form, materials, geometries, cultural significance, energy consumption, carbon dioxide emissions, indoor climate) as well as the outdoor climate (such as local weather and climate change predictions).

The availability, completeness and quality of the data about a historic district can vary significantly. The DSS has therefore been designed so that it can handle these different levels of detail in the data. Where no location specific data is available, the DSS will make available general information about the retrofitting of historic districts in Europe, such as a collection of retrofit case studies [5] and details about the relevant heritage protection systems [6].

Where data is sparse, the assessment is made using 'transferable models': Based on the climatic region and twelve set questions, the DSS outputs general retrofit recommendations depending on city type and climatic context. This is referred to as 'level 1' assessment.

For urban districts where at least some suitable data is available, it will be collated into a spatial multi-scale data model. Most of the time, the analysis by the DSS will be based on selected sample buildings that are representative of the district ('level 2' assessment'). To help identify these sample buildings, EFFESUS has also developed a Building Stock Categorisation Tool (BSCT), which is another web-based software [7].

Ideally, detailed data will be available for each and every building. In this case, the use of the Building Stock Categorisation Tool could be omitted and the full data model be used as a DSS input. Such analysis could be thought of as 'level 3' assessments, which, due to their complexity, have not (yet) been integrated into the DSS. The different assessment levels discussed above are summarised in Table 5, together with the tools used and outputs given. The relationship of software tools and data inputs and outputs for level 2 assessments is illustrated in Figure 38.

In the following, the testing of the DSS and the Building Stock Categorisation Tool will be described. The testing was carried out in early 2016, when the software programmes were nearing completion.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

Detail level	Availability and quality of location-specific data inputs	Use of data model	BSCT	Technical Repository
0	Geographic location as the only district data input	not used	not used	partially used
1	Geographic location and identification of corres-ponding city type through a guided process of set questions and answers	not used	not used	partially used
2	District data generally available, but incomplete and/or of limited quality	used	used	fully used
3	District data available, (near-) complete and of good quality	used	not used	fully used

Table 5: Detail levels used in DSS assessment, depending on data availability, completeness and quality, in conjunction with a data model, the Building Stock Categorisation Tool (BSCT) and the Technical Repository

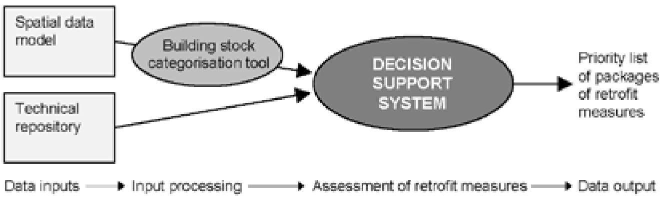


Figure 38: For level 2 assessments, two datasets are inputted into the DSS generating as output priority lists of retrofit measures; the data size in the spatial data model is reduced through the building stock categorisation tool

Software testing

The software tools were tested regarding their functionality, user-friendliness and suitability. The aspects tested included energy and economy (including carbon dioxide emission and financial costs), suitability in a historic context (including cultural significance and material compatibility) and environment impacts (on indoor and outdoor environments).
Firstly, the DSS web portal was reviewed and suggestions made for improvements to its layout and content. This included a general review regarding the usefulness of the information planned for dissemination as DSS outputs where no suitable district data is available.
Secondly, level 1 assessments were tested using the cities of Santiago de Compostela in north-western Spain, and Visby in south-eastern Sweden

at the island of Gotland. The questionnaires were answered as required by the DSS and the outputs evaluated regarding their general applicability and usefulness. As no district data is used in level 1 assessments, no location-specific outputs are produced, such as energy savings or capital costs.

Lastly, level 2 assessments were performed. These are far more onerous compared to the previously conducted testing. Again, the cities of Santiago de Compostela and Visby where used, but this time, spatial data models were created prior to commencement of the testing. The Spanish model was based on the historic city centre of Santiago; the Swedish model only included three urban blocks of Visby's historic city centre (both city centres are UNESCO World Heritage Sites). The data in the models were analysed and reduced, using the Building Stock Categorisation Tool: For Santiago, three sample buildings were selected to represent the entire historic city centre; for Visby, two buildings were chosen (Figure 39). In this process, general suggestions for improvements to the categorisation tool were made.

Figure 39: Building stock categorisation: from whole district data to data for representative sample buildings

The identified sample buildings were tested by using them in the DSS and analysing the resulting data outputs. The software, firstly, generates a list of retrofit measures, which it considers applicable in the particular location-specific context (Figure 40). This list was found to be generally suitable. The identified measures were then ranked manually and by using two ranking systems built into the DSS:

- Analytic Hierarchy Process (AHP) and
- Simple Multi-Attribute Rating Technique (SMART).

They allow software users to set priorities regarding indoor air quality, disruption, thermal comfort, energy saving and associated costs (Figure 41). The ranked priority lists of retrofit measures were found to produce suitable results; the associated quantitative calculations (including energy consumption, savings, costs) were plausible. The two data models were also tested for a second time with their climate data swapped. This means that the Santiago model was tested as if the city were in south-eastern Sweden; and the Visby model as trialled as if located in north-western Spain. The DSS outputs were found to have changed suitably due to the climate data swap.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

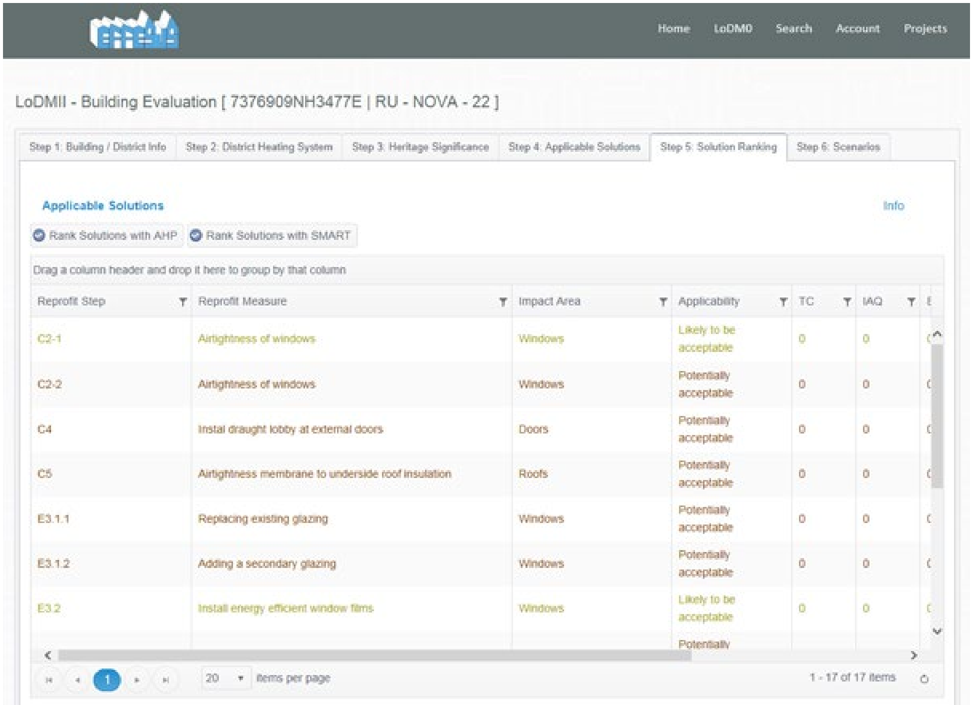


Figure 40: DSS screenshots listing applicable retrofit measures for a specific location

Continuation of the software development

The DSS will require further demonstration in the field before it can be used extensively. Further adaptations and improvements to the software are certainly possibly and will need to be tied closely to the business model (which is still under development at the time of writing of this article) under which the software is to be used.

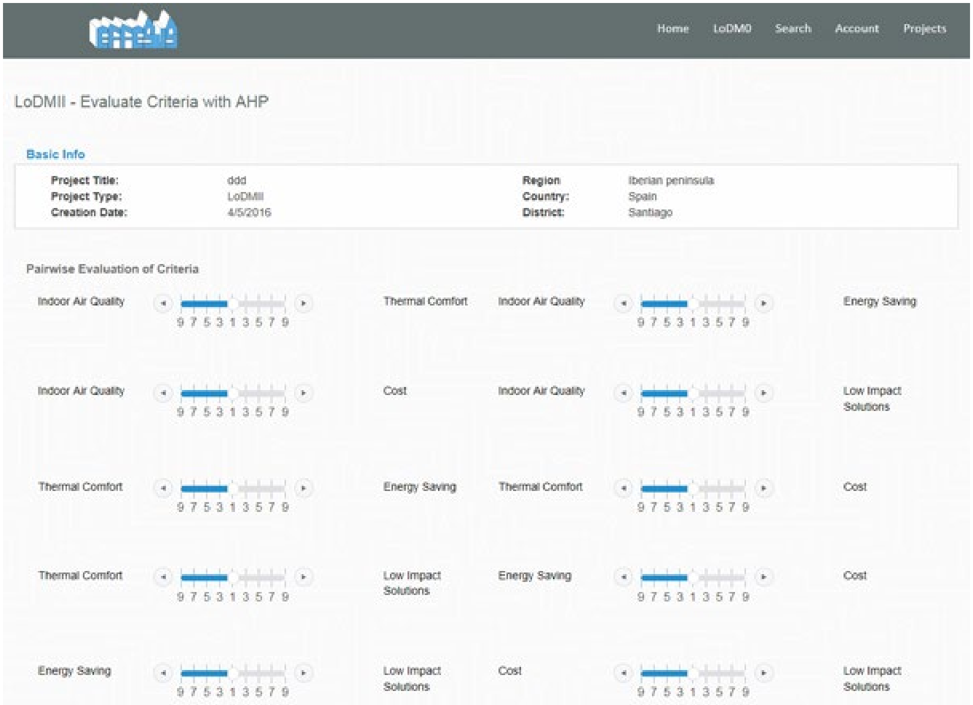


Figure 41: DSS screenshots showing the AHP system for ranking retrofit measures

Current restrictions for use of the DSS include:

- A spatial data model needs to be produced before the DSS can be used for level 2 assessments. However, there is no tool available for doing this easily.
- Although the Building Stock Categorisation Tool (Figure 42) has proved itself as an excellent tool to analyse urban district data, the selection process of sample buildings is still a manual activity and would benefit from automatisation.
- The assessment of technical compatibility, including reactions of materials in contact and reversibility of interventions, is not yet fully integrated.
- The assessment of embodied energy has not been implemented yet for reason of complexity, thereby preventing the use of full life-cycle analysis.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

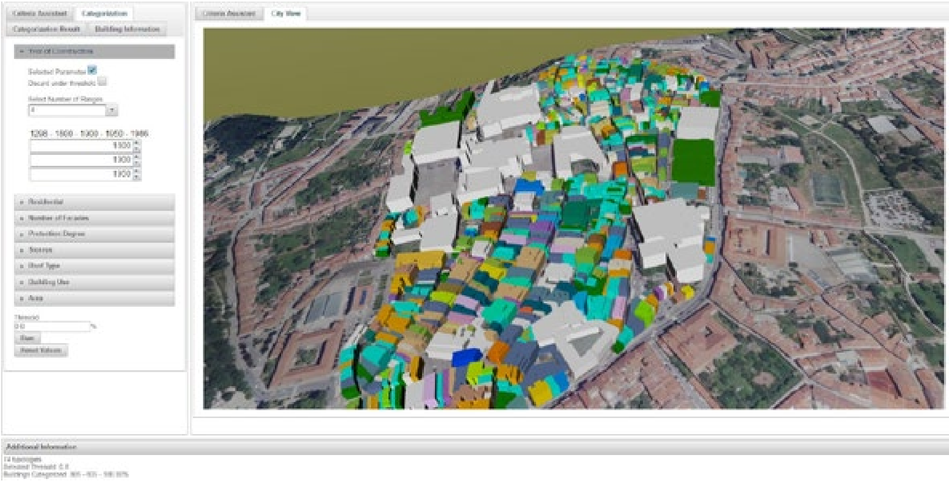


Figure 42: Screenshots of the Building Stock Categorisation Tool, developed as part of EFFESUS to analyse urban district data with the aim to select a number of identified sample buildings representing an entire urban district

Conclusions

The EFFESUS project has produced a sophisticated DSS to aid city planning experts in the process of making strategic decisions on improving energy performance of buildings at an urban scale. The DSS is supported by a Building Stock Categorisation Tool which allows for the excellent analysis of urban district data. The DSS is generally user friendly, its outputs are plausible and suitable. It is in the nature of the software though that not all recommended retrofit measures are always suitable in real world situations. The ranked priority lists of retrofit measures produced for location-specific assessments require critical review by professionals understanding the particularities of the historic buildings and districts concerned. How the DSS will effectually be used depends on the business model, currently being developed for the software tool.

References:

[1] Energy Efficiency for EU Historic Urban Districts Sustainability (EFFESUS), 2012 to 2016, cofunded by the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement number 314678. Details are available at: http://www.effesus.eu

[2] EFFESUS Decision Support System, available at: http://95.129.41.62:8080/

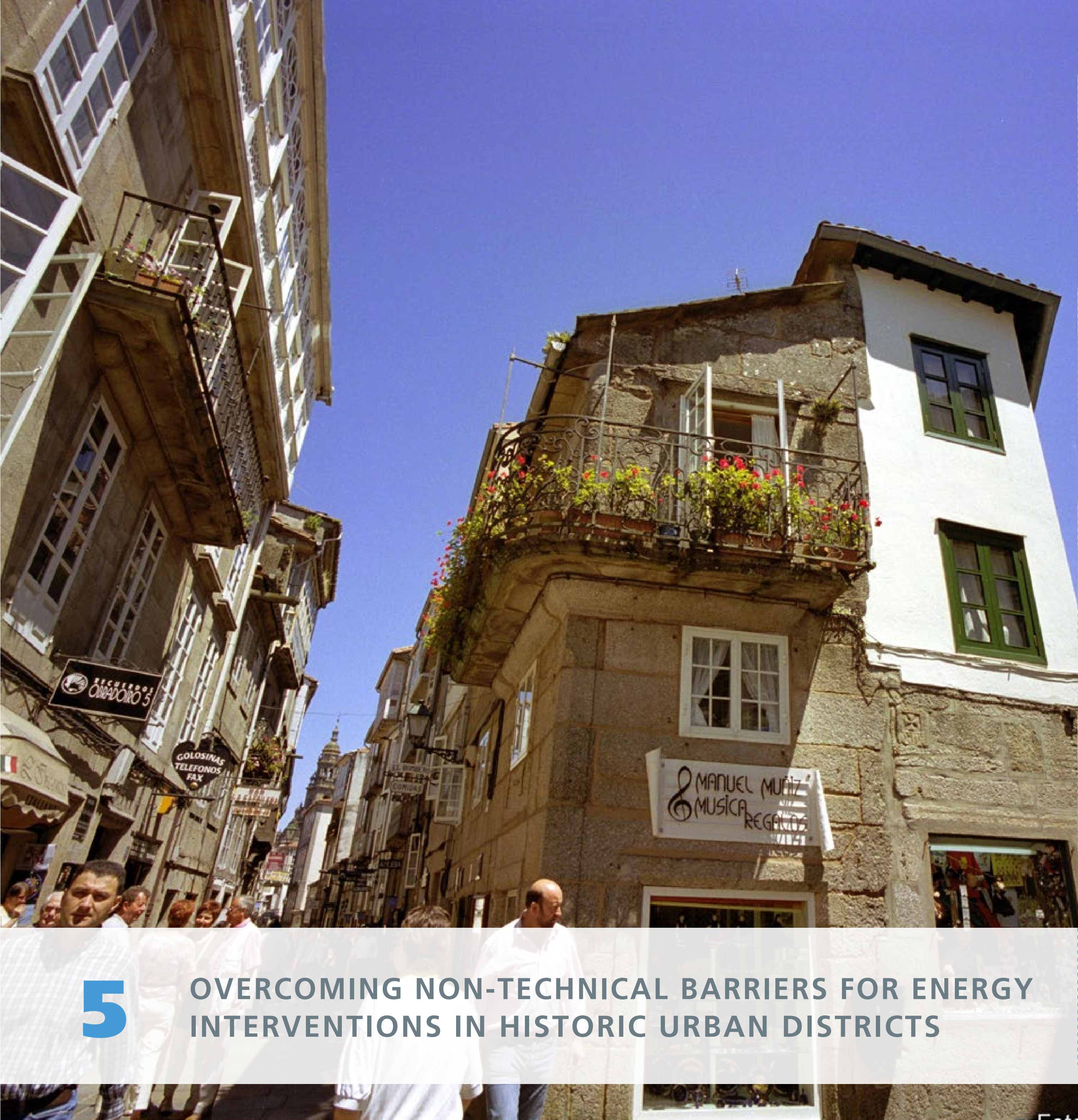
[3] Egusquiza, A., Brostrom, T., Pagliula, S., Hermann, C., Rodwell, D. (forthcoming): Strategic assessment of historic cities for energy efficiency retrofits to enable their long-term use and conservation: Development of the EFFESUS methodology and software tool. In: ICOMOS Poland (forthcoming): Heritage in Transformation.

[4] EFFESUS Technical Repository, available at: http://www.dappolonia-innovation.com/Effesus5/

[5] EFFESUS Best Practices for Energy Interventions, available at: http://95.129.41.62:8080/general-information/best-practices/

[6] EFFESUS European and National Policies, available at: http://95.129.41.62:8080/general-information/european-and-national-policies/

[7] EFFESUS Building Stock Categorisation Tool, available at: http://3dcity.tecnalia.com/Effesu-sAppV2/faces/CategorisationTool.xhtml?userId=1&projectId=2&city=effesussantiago



5 OVERCOMING NON-TECHNICAL BARRIERS FOR ENERGY INTERVENTIONS IN HISTORIC URBAN DISTRICTS

5. OVERCOMING NON-TECHNICAL BARRIERS FOR ENERGY INTERVENTIONS IN HISTORIC URBAN DISTRICTS

While the focus in EFFESUS has been on the development of heritage-compatible technical innovations and the creation of a software-based Decision Support System, the project has also dealt with questions concerning how to overcome various non-technical barriers for energy interventions in historic urban districts. These kinds of barriers can be different in nature: namely financial, cultural, societal or political. Financial barriers are closely related to the non-availability of appropriate funding schemes and public financial incentives to overcome the lack of financial capacity of house owners. Cultural barriers exist, for example, in terms of contradictory understanding of architectural traditions and typologies of urban regeneration among the different stakeholders involved in these processes; while retrofitting of multi-occupancy house can be a societal challenge due to the often diverging interests of the various owners. Political barriers can be the result of non-activity on the part of the municipal administration in energy planning and management of larger-scale urban retrofit measures. The following two contributions provide an overview of the most important non-technical barriers, which currently affect the retrofit of historic buildings in Scotland and in Santiago de Compostela, and recommendations how to overcome them in practice.

Apart from these non-technical barriers, directly related to energy interventions in historic urban districts, EFFESUS has dealt with specific non-technical barriers with regard to the implementation of the project's objectives. The final contribution in this chapter, therefore, is aimed at providing insights into the non-technical challenges in implementing the seven EFFESUS case studies. In addition, it describes crucial challenges with regard to international market implementation of the heritage-compatible innovations developed in EFFESUS.

5.1 NON-TECHNICAL BARRIERS TO RETROFITTING HISTORIC BUILDINGS AND URBAN DISTRICTS IN SCOTLAND

Novel and adapted retrofit products make it possible to improve the energy performance of historic buildings in ways that are sustainable and have no adverse impact on the characteristics that constitute their cultural importance. Some limitations, however, remain: Inappropriate retrofits can cause accelerated deterioration of building materials, create harmful indoor environments and reduce a building's cultural significance. Despite this, appropriate retrofit measures are now often available to choose from when retrofitting a historic building. Yet, their uptake is slow.
Often, it is not only technical barriers that hinder a building's retrofit, but non-technical barriers of financial, cultural, societal or political nature. This contribution seeks to provide an overview of the non-technical barriers which currently impact on the retrofit of historic buildings in Scotland. The overview is based on: research performed by the EFFESUS project [1], including discussions at an EFFESUS expert stakeholder workshop in Glasgow in February 2015 (Figure 43); outputs of the LEAF project [2], led by the Scottish sustainable development organisation Changeworks; and own professional experience. The presented overview does not aim to be inclusive, but rather to show the large variety of aspects that can constitute a non-technical barrier. Because this overview was produced for a project concerned with historic urban districts, the focus here will also be on an urban context and scale; and due to the sources used, the overview will concentrate on Scotland and on residential properties. Some of the discussion will be applicable to the other parts of the United Kingdom of Great Britain and Northern Ireland (UK); and many issues discussed will also be transferable to other places in Europe. The non-technical barriers to be described have been grouped as financial, cultural, societal and political [3].

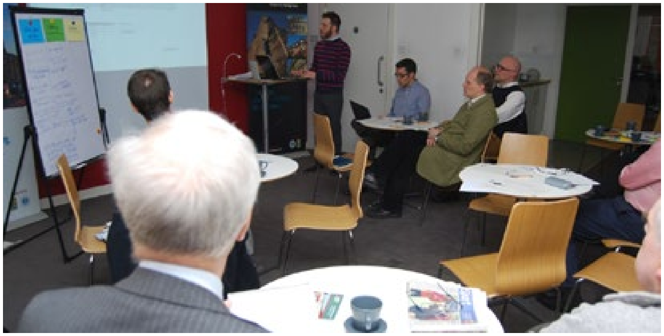


Figure 43: EFFESUS stakeholder workshop in Glasgow to discuss non-technical barriers impacting on the energy-related retrofit of historic buildings and urban districts

Financial barriers

With regard to financial barriers, the UK tax system incentivises the construction of new residential property over the improvement of existing buildings. While the standard rate (20%) of Value Added Tax (VAT), generally, applies to building construction, new residential buildings can be exempt from VAT [4]. The retrospective installation of "energy-saving materials" attracts VAT, albeit at a reduced rate of 5%, except where their installation forms part of a major replacement, for example where a building is reroofed. In that case, 20% VAT applies to the roof's new covering and insulation [5]. No specific rules exist for historic buildings [6,7]. The tax system, thereby, incentivises energy performance improvements but favours even more new construction and building replacement.
Similarly, governmental incentives in Scotland for owner-occupiers to purchase residential property through Scotland's Help To Buy scheme are only applicable to new construction [8], and improvements to the public schools estate, the Schools for the Future programme, focuses on building replacement rather than retrofit [9]. Governmental support for improvements of energy performance of existing housing has been

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

criticised for creating a quickly changing funding landscape [10]: The UK government launched, in 2013, the Green Deal scheme [11]. It provided for the installation of selected retrofit measures through approved energy utility companies at no upfront capital cost to home owners, who repay the cost long-term through their energy bills. The scheme was replaced a year later by the Green Deal Home Improvement Fund, which also lasted only a year and has had no replacement [12,13]. The governmental support was described as "a triumph of short-termism" [14] unhelpful for the construction industry. The Green Deal was also criticised with regard to its suitability for older, often historic buildings, generally built using moisture-managing construction forms [15]. Identifying suitable Green Deal retrofit measures turned out to be not only challenging technically, but also economically: Green Deal assessments were based on energy cost savings calculated with Reduced Data SAP (RdSAP), a tool developed for the energy performance benchmarking of buildings [16]. Also used to generate energy performance certificates (EPCs), the tool, however, does not provide realistic assessments of the in-use energy consumption of older buildings [17,18,19].

Another financial retrofit barrier is the fact that, to date, the energy performance of properties does not influence property prices significantly, although it is mandatory to provide EPCs when letting or selling residential properties [20]. In Scotland, prices are still predominantly determined by location and number of bedrooms. This lack of influence of a property's energy performance on its prices is a disincentive to making energy-related improvements. Furthermore, EPCs for residential properties are calculated with RdSAP, the limitations of which for the assessment of older buildings are mentioned above.

Cultural barriers

Apart from the financial aspects, various cultural barriers exist, many of which relate to the multiple ownership of buildings. Scotland has an old, distinct urban tenement tradition (Figure 44). Whereas "43% of Europeans live in flats" [21], only 30% of Scots do so [22], which, however, is still a large portion of the population compared to 15% in England and 8% in Wales [23]. Yet, despite this tradition, Scotland does not have mandatory forms of associations of the owners of a tenement. In Germany, for example, property owners are legally obliged to establish residential property owners associations (in German: Wohnungseigentümergesellschaften) to deal with common building maintenance [24]. In Sweden, tenant-owner associations (in Swedish: bostads-rättsförening) are not uncommon for buildings which are owned jointly by occupiers [25]. As part of the German or Swedish systems, owners are generally required to make regular payments into a common fund in order to cover the costs of on-going building maintenance and future repairs. Such communal systems can then also be used for joint investments into energy performance improvements.

The general absence in Scotland of such forward-looking owners' associations means that routine building maintenance and repair are difficult to organise; joint energy performance improvements are even more difficult. Yet, carrying out works collectively often reduces capital

Figure 44: Two multistorey tenement buildings (on the right of the photo), built in the 1720s, on North Bank Street in Edinburgh's Old Town, part of a World Heritage Site

costs (for example: scaffolding is only needed once if works to a façade are carried out jointly), and many improvement measures only become feasible when installed and used communally (particularly systems for energy generation from low-carbon or renewable sources, such as heat pumps or solar panels). Professional property management of buildings in multiple ownership, referred to in Scotland as 'property factoring', is more common in Glasgow [26, 27], for example, than in Edinburgh. Such factoring could also be used as an organisational and financial vehicle for energy-related retrofits in the absence of building owners' associations. For this reason, the LEAF project lists as a policy recommendation the "implementation of [building] maintenance plans and improved management structures in multi-occupancy buildings" [28].

Societal barriers

Retrofit issues also arise from the often diverging interests of the owners of buildings in multiple ownership. The owners are rarely a homogeneous group, but a mix of owner-occupiers and short- and long-lease landlords, and of different age groups and household forms (for example: couples, families, flatshares, widowers). The owners have often different and opposing interests on how to develop their properties, and energy performance improvements are not necessarily an investment priority. Young property owners, for example, might not plan to stay in the property for long enough to make retrofit measures financially viable, particularly those requiring high capital investment and with long payback periods. The same is true for elderly owners, as their often reduced income and remaining life expectancy might make long-term investments not worthwhile [29]. Landlords, generally, have little incentive to invest in energy performance improvements of their properties, as this will not save them money; the energy savings will only benefit their tenants. It remains to be seen to which degree forthcoming UK regulations requiring minimum EPC ratings for the rental and sale of residential properties will act as an incentive for owners and developers to invest in energy performance improvements [30,31].

Political barriers

Communal installation of retrofit measures at a building scale makes options available which would not be feasible for singular flat owners. The same is also true at higher scales: Joint retrofits on a neighbourhood or urban district level allow the installation of energy-related systems that are not possible at the scale of single buildings, such as combined heat and power (CHP) plants and district heating systems. The latter is, for example, used in the historic city centre of Visby, a UNESCO World Heritage Site on the Swedish island of Gotland [32], where a distribution network was installed below the centre's street surfaces (Figure 45).

Figure 45: Installation of a district heating system below the streets of Visby's historic city centre, a World Heritage Site (Image © GEAB)

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

Initiatives of this scale are rare in urban Scotland. With regard to CHP plants, for example, only few have so far been installed, mostly at university and sports campuses. The University of Edinburgh, for example, powers its Edinburgh campuses with four CHP plants, feeding a district heating system [33] which, however, remains disconnected from the adjacent historic city. A rare example for urban-scale retrofit in Scotland is the installation by Cube Housing Association in 2012 of a district heating system with CHP plant at the mid-20th century Wyndford Housing Estate in Glasgow, serving nearly 2000 homes in three-storey terraced buildings and fifteen-storey high-rise towers [34]. The installation of Visby's district heating system was greatly supported by the Government of Gotland Region. It seems that, unless Scotland's public administrations start taking a more active role in energy planning and management also, such larger-scale urban retrofits will not become commonplace in Scotland.

Conclusions

Numerous non-technical barriers exist to the retrofitting of existing buildings, with some barriers particularly applicable to older and historic buildings. The above discussion has given an overview of the nature of these barriers. Completeness was not the aim for the presented overview, but rather highlighting the multitude of aspects which can and need to be considered: from financial to cultural, societal and political. Overcoming the technical barriers to building retrofit has been the topic of numerous research projects. Yet, whilst technical barriers remain of relevance, a better understanding of the non-technical barriers to energy-related building improvements is needed to integrate it more systematically in governmental policy development.

References:

[1] Energy Efficiency for EU Historic Urban Districts Sustainability (EFFESUS), 2012 to 2016, cofunded by the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement number 314678. Details are available at: http://www.effesus.eu

[2] Low Energy Apartment Futures (LEAF), 2014 to 2016, cofunded by the Intelligent Energy Europe Programmed of the European Union. Details are available at: http://www.lowenergyapartments.eu

[3] The LEAF project uses the following grouping: funding and finance; motivation and engagement; property and regulatory issues; communication and decision-making.
LEAF project partners (2016): Improving the energy performance of apartment blocks: Low Energy Apartment Futures (LEAF): Final report: 3. Available at: http://www.lowenergyapartments.eu/wp-content/uploads/2016/03/LEAF_Final_Report_D1.1_Mar16.pdf

[4] Her Majesty's Revenue and Customs (2014): Buildings and construction. (HMRC VAT Notice, 708) [webpage] Available at: https://www.gov.uk/government/publications/vat-notice-708-buildings-and-construction/vat-notice-708-buildings-and-construction#zero-rating-approved-alterations-to-protected-buildings
Also VAT exempt are conversions to residential use for housing associations; otherwise, such conversions attract 5 % VAT, as do renovations and alterations of empty residential buildings.

[5] Her Majesty's Revenue and Customs (2014): Energy-saving materials. (HMRC VAT Notice, 708/6) [webpage] Available at: https://www.gov.uk/government/publications/vat-notice-7086-energy-saving-materials/vat-notice-7086-energy-saving-materials

[6] Seely, A. (2012): VAT on historic building repairs. (Library House of Commons Standard Note, 1450): Available at: http://researchbriefings.files.parliament.uk/documents/SN01450/SN01450.pdf

[7] Kindred, B. (2014): Policy regarding Value Added Tax (VAT) on historic buildings. (IHBC Research Note, 14.1) version 300514. Available at: http://ihbc.org.uk/resources/researchnotes/files/IHBC%20Research%20Note%201%20Policy%20regarding%20VAT%20on%20Historic%20Buildings%20141v300514.pdf

[8] Scottish Government (2016): Help to Buy (Scotland) Affordable New Build Scheme. Available at: http://www.gov.scot/Topics/Built-Environment/Housing/BuyingSelling/help-to-buy

[9] Scottish Futures Trust (2016): Scotland's schools for the future: Inspiring learning, aspiring nation. Available at: http://www.scottishfuturestrust.org.uk/our-work/sft-build/schools-for-the-future/

[10] For example, the LEAF project has found "lack of Government subsidies and changing funding landscape" to be a core issue hindering tenement retrofits. (LEAF project partners (2016): ibid.)

[11] Her Majesty's Government (2016): Green Deal: Energy saving for your home. Available at: https://www.gov.uk/green-deal-energy-saving-measures/overview

[12] Canocchi, C. (2014): Green Deal scheme shut down after households grab all £120 of energy efficiency handouts in just six weeks. This Is Money. 25 Jul. [webpage] Available at: http://www.thisismoney.co.uk/money/bills/article-2705431/Government-closes-120m-Green-Deal-scheme-funds-runs-out.html

[13] Vaughan, A. (2015): Government kills off flagship green deal for home insulation. The Guardian, 23 Jul. [online] Available at: http://www.theguardian.com/environment/2015/jul/23/uk-ceases-financing-of-green-deal

[14] Carrington, D. (2015): Green deal cashback scheme is shut after surge of applications. The Guardian, 25 Jul. Available at: http://www.theguardian.com/environment/2014/jul/25/green-deal-cashback-scheme-is-shut-after-surge-of-applications

[15] Little, J., Ferraro, C., Arregi, B. (2015): Assessing risks in insulation retrofits using hygrothermal software tools: Heat and moisture transport in internally insulated stone walls. 2nd ed. (Historic Scotland Technical Paper, 15): 67-70. Available at: http://www.historic-scotland.gov.uk/technical-paper15.pdf
[16] Reduced Data SAP (RdSAP) is a simplified form of the Standard Assessment Procedure (SAP), which is the ‚National Calculation Method' selected by the UK government to fulfil the European Directive on the Energy Performance of Buildings.
[17] Barnham, B., Heath, N., Pearson, G. (2008): Energy modelling analysis of a traditionally built Scottish tenement flat. (Historic Scotland Technical Paper, 3). Available at: http://www.historic-scotland.gov.uk/technicalpaper3.pdf
[18] Ingram, V., Jenkins, D. (2013): Evaluating energy modelling for traditionally constructed dwellings. (Historic Scotland Technical Paper, 18). Available at: http://www.historic-scotland.gov.uk/technicalpaper18.pdf
[19] The LEAF project recommends for policy development "improvements to EPC methodology and applicability" and "changes to the format and content of EPC reports" (LEAF project partners (2016): ibid.: 4.)
[20] Unpublished research by the Energy Saving Trust for the Scottish Government, 2012.
[21] Eurostat 2011. Quoted at: LEAF project website (2016): The percentage refers to the 27 EU member states.
[22] National Records of Scotland (2011): Scotland's Census (2011): Accommodation type: People. (Table, QS401SC) Available at: http://www.scotlandscensus.gov.uk
[23] Office of National Statistics [UK government] (s.d.): Census 2011: Dataset QS401EW: Accommodation type – People. Available at: http://www.ons.gov.uk/census/2011census/
[24] Wohnungseigentumsgesetz of the Federal Republic of Germany, §§10-19. Available at: http://www.gesetze-im-internet.de/woeigg
[25] Skanska (2013): Living as a tenant-owners: Your guide to your new home. Dec. Available at: http://bostad.skanska.se/Services/FileStoreProxy/GetFile.ashx?id=dd9a7fe9-9fee-4317-8724-ed-24f836f6c8
[26] Scottish Government (2015): Property factors. Jun. [website] Available at: http://www.gov.scot/Topics/Built-Environment/Housing/privateowners/propertyfactors
[27] Glasgow City Council (s.d.): Glasgow's Factoring Commission. Available at: https://www.glasgow.gov.uk/index.aspx?articleid=18252
[28] LEAF project partners (2016): ibid.
[29] The LEAF project, for example, found in its case study in Frankfurt upon Main, Germany, that "Long payback periods [of retrofit measures] appeared to be a particular problem for elderly residents, but their motivation was more focussed on improving indoor comfort." (LEAF project partners (2016): ibid.: 22.)
[30] UK parliament (2015): The Energy Efficiency (Private Rented Property) (England and Wales) Regulation 2015. (2015 no. 962). Available at: http://www.legislation.gov.uk/uksi/2015/962/pdfs/uksi_20150962_en.pdf
[31] Vaughan, A. (2015): Landlords to be banned from letting draughtiest homes. The Guardian. Available at: http://www.theguardian.com/environment/2015/feb/05/landlords-draughty-homes-ban
[32] Region Gotland (2013): Biofuel in Visby's district heating. Available at: http://www.visby.se/54546
[33] Somervell, D. (2013): Trigeneration at University of Edinburgh: Combined heat and power (CHP) / district heating. Feb. Available at: http://www.ed.ac.uk/polopoly_fs/1.134640!/fileManager/UoE%2520CHP-DH%2520Case%-2520Study.docx
[34] Edina (2012): Wyndford Housing Estate. 02 Dec. Available at: http://www.edina.eu/page/89/Wyndford-Housing-Estate.aspx

5.2 CITIZEN PARTICIPATION IN SANTIAGO

One of the main challenges with regard to the management of historic centres is to encourage the active participation of the inhabitants living in these areas. Focusing on energy rehabilitation is one of the best ways to boost participation, as it directly affects citizens and the living conditions of the buildings in which they live.

Owners are responsible for ensuring the proper conservation of their buildings, and energy efficiency and maintenance programmes require their participation. Retrofitting from the energy point of view can be an opportunity to involve citizens in complex urban regeneration processes, as it requires the commitment of residents to directly undertake rehabilitation mechanisms in order to maintain their homes.

One of the tasks of EFFESUS was to promote an energy workshop for the inhabitants of the historic centre of Santiago de Compostela. This workshop has been organized by the Consorcio de Santiago to the objective of setting up an "Urban Energy Laboratory" in the historic city centre. The Consorcio de Santiago has been stimulating various rehabilitation programmes during the last 20 years with great acceptance among the inhabitants, and it will now develop a programmes to advise citizens on the energy characteristics of their buildings and homes. This laboratory, a component of the ongoing rehabilitation programmes, will give advice on possible energy solutions for each individual dwelling, through the exchange of information between professionals and inhabitants interested in innovative results.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

The Urban Energy Laboratory will be located in a commercial office in the heart of the historic city. In addition to assisting citizens in energy rehabilitation, the laboratory will contribute to improving knowledge on how buildings are used, managed and transformed to meet modern comfort requirements, as well as to collecting information on energy consumption and housing environmental management strategies. The laboratory will also foster key knowledge for visitors, by explaining and illustrating options for how to handle the permanent transformation processes in historic centres without endangering the urban heritage values they represent. This is because the continued success of historic cities is directly related to their capacity to evolve and adapt to changes in the everyday lifestyles of their inhabitants; the continuity of liveable historic cities depends on their ability to change and enhance the conditions for citizens.

Figure 46: Typical dwelling in Santiago de Compostela

Against this background, what are the appropriate steps for changing and improving living standards without damaging heritage values? In our opinion, the response can be related to energy and to the culture of maintenance, on the capacity of the buildings to allow changes easily, and the ability to create jobs and boost the local economy through the processes of urban transformation.

Citizens living in historical areas have hitherto been effectively marginalised by the processes of protection and enhancement of their physical surroundings. Authorities have often vehemently told owners what they could not do in their homes or districts, whilst not explaining what they could do or how they could do it. Therefore, it is necessary to focus on the procedures and processes based on the everyday life of the inhabitants of cities and neighbourhoods, through simplified bureaucracy, and direct and close cooperation with residents.

There is a clear parallel between the loss of heritage and the loss of energy values, as traditional living models and architectural and urban features were adapted to the environment. Instead of rehabilitation, it seems advantageous to talk about liveability. The evolution of cities and human progress has always been related to the improvement of liveability conditions; and liveability requires energy. Pre-industrial architecture can be considered as a model of efficiency and economy in terms of basic liveability in homes and public spaces.

It is not possible to deal with commitments on the reduction of consumption and emission of greenhouse gases without reviewing the lessons learned in architecture and urbanism in historic cities. The approach to the rehabilitation and conservation of the urban heritage is assuredly and strategically possible if considered from an energetic point of view.

Energy and preventative maintenance for the preservation of the historic city can only be managed from the active involvement of users. Therefore, it is urgently necessary to engage citizens in the preservation of heritage and to replace the culture of dependence by a culture of commitment.
If we admit that a city is continuously changing, we should consider urban rehabilitation as a process which has to respect the rhythm and continuity of this state of permanent transformation. Hence, in historic cities, even apart from their heritage values, methodologies for intervention must necessarily be tempered to the daily reality of the city and its inhabitants in order to be adapted to this complex scenario of continuous change. It is not easy, but this is the real challenge of urban regeneration. Moreover, urban science, as it has been developing during the twentieth century, has not convincingly handled the simple complexity of everyday life in cities.

Figure 47: Citizen workshop in Santiago

Unless there is a culture of sound urban governance, it is time to start thinking that the systems and procedures of urbanism are not enough. Neither intensive projects, copiously financed, nor urban planning strategies conforming to standard management formulas have been able to fit peacefully in the natural, evolutionary transformation of cities. In historical centres with special cultural value, protection formulas in the last third of the 20th century were dissociated from the reality of cities and, distinctly worse, from their inhabitants. They have reached dimensions of extraordinary ineffectiveness with respect to the primary objectives of conservation, and sometimes they became a factor of significant heritage loss in the city as a whole. This is why it is urgent to reformulate strategies of conservation and enhancement of the historic cities through the promotion of good urban governance.

Within the framework of the policies of urban regeneration that drive the Consorcio de Santiago, and in coordination with the actions planned in EFFESUS, the Urban Energy Laboratory and workshop "Refurbish With Energy!" was held for a week with the involvement of the inhabitants of the city who feel committed to the intelligent management of energy in their homes. In parallel with the citizen workshop, the children's workshops "Learn & Play With Energy Efficiency!" was held, to the purpose of involving the young inhabitants of the city in something that will be decisive in their lives.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

5.3 OVERCOMING IMPLEMENTATION BARRIERS IN TRANSDISCIPLINARY RESEARCH PROJECTS

A successful energy-efficient retrofit of a historic urban district is a process which requires the stamina of all stakeholders, as success can only be achieved with the cooperation of public authorities, private enterprises, private owners, investors and residents. With this knowledge, EFFESUS initiated several activities dedicated to overcoming some of the major implementation barriers which arise in multi-disciplinary retrofit projects. These efforts focused both on facilitating the conduct and coordination of the project activities in the seven case studies and on the potential market implementation of the heritage-compatible innovations developed in the project.

Case-Study implementation

The project outcomes show that the number of implementation barriers correspond to the complexity of the interventions that were undertaken in the seven EFFESUS case studies. The project partners responsible for implementing interventions on the district level had to deal with the quite different expectations and interests of various stakeholders. For example, the comfort conditions under current circumstances in the investigated case studies are relatively high. It was therefore quite difficult to convince citizens to agree to change their current energy systems or to implement measures to improve energy efficiency. As research in this area has consistently shown, most people are not motivated by the concepts of 'energy efficiency' or 'sustainability'. Most people need to understand that they will have more direct benefits before they will engage with concepts which are perceived as only having an indirect or general impact on them.

One tool to address this challenge is to offer showcases, where citizens can test the living conditions in historic buildings following the introduction of innovative technologies. Moreover, it has been concluded during the case study implementation that there is often a lack of good and neutral information, and citizens are not well informed about how much energy they use. To improve this knowledge, charts and other visual summaries of the typical energy use in an average household in their historic district over some years would be very helpful. Moreover, reliable information from a trusted and independent source on the investment and maintenance costs of selected technologies, together with information on the expected savings due to reduced energy use, is necessary in order to convince people to make changes and investments.

Another important challenge for working on a district level are the local administrative procedures, which are often slower than expected. Hence, the involvement of the local administration from the very beginning is of utmost importance, as one should not underestimate the time for building trust with a local administration for such activities. This is also true for negotiations with the owners or the property management of individual buildings, in particular if interventions in listed buildings are planned.

The main challenge in urban analysis case studies is data availability in municipality's databases. The partners, therefore, had to make estimations and on-site measurements in order to obtain valid data. This is time-consuming but unavoidable, as it is generally the case that people do not know how much energy their buildings use and how they use this energy.

In summary, although the project has involved stakeholders at an early stage for the case studies, the main recommendation for overcoming the barriers to implementation is to involve the local administration, heritage authorities and property owners at an even earlier stage to achieve the necessary permissions for retrofit interventions. In most cases, their involvement at least a year before the planned interventions is necessary. The activities of building trust and exchanging information with the local authorities and building management have to be continuous to achieve success, including beyond the completion of individual projects.

Market implementation of EFFESUS innovations

In order to market the heritage-compatible innovations developed within the EFFESUS project, the following considerations are considered crucial:

- Development by companies of market-specific business models for their new products
- Recognition that market prediction and turnover estimates for new products are not easy
- Anticipate internationalisation of the business model to expand the market potential

As mentioned above, it is often difficult to convince citizens to change their current energy systems and to implement measures to improve energy efficiency. People may say that they want to protect the environment, but real decisions are influenced by other criteria, for example to increase the value of their property, to save money, or to increase their comfort levels. For this, market-specific business models have to be developed. People have to be convinced that they will benefit due to the use of energy efficient products, even if the innovation is more expensive than conventional products. Building owners therefore need information to calculate the total return of any investment, including increased comfort and healthy living or working conditions in addition to reduced monetary costs and increased values. A useful methodology to develop new business models is to use the Osterwalder "Business Model Canvas"[1],

5

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

which supports the creation of numerous new models in a short time. In this way, more than one model can be developed and different ideas discussed, a necessity in order to explore and understand the full market potential of any new product.

The Osterwalder canvas addresses a "business as usual" approach, which focuses on profit as the only objective of any enterprise. The EU's funding of the EFFESUS project is directed at supporting its policies of developing a sustainable society and mitigating the impacts of climate change through reduced carbon dioxide emissions; EFFESUS is focused on the specifics of energy efficiency and renewable energy in historic urban centres. It is therefore necessary to look beyond the "business as usual" approach and work with innovative tools which support the development of sustainable business models.

Fortunately others have taken Osterwalder's basic idea and added additional layers of information and investigation which put the environment at the centre of the business model, not financial gain. The "Circular Design Canvas" [2] has 13 sections, whereas Osterwalder's business canvas has nine. The "Flourishing Business Canvas" [3] has 16 questions organised in three layers representing Environment, Society and the Economy, with Environment as the foundation. This is a more complex but necessary approach if we are to develop innovative business models for a sustainable future.

It is difficult to make market predictions when entering a market with a new product, and especially to estimate turnover. Therefore, it is necessary to conduct a deep market analysis first. For this, data about the total number, the age and the status of the historic buildings of the target market are needed. Given this information, it is possible to estimate the market share and the quantity of sales; the price for the products must also be established. For this it is necessary to know the internal cost of production (direct costs, fixed costs, profit margin). Producers also have to consider that there is a market price, namely the price customers pay for similar existing products. Because there are assumptions in the calculation and the input data have uncertainties, it is reasonable to calculate different scenarios of financial analysis. In this, it is important to keep in mind that the aim of the calculation is not the prediction of the future, but the analysis of whether a business model is realistic.

Inherent in the innovation and uniqueness of new products is the opportunity for producers to enter international markets to increase their sales. Some challenges are connected with this decision, including language, different rules and legislation, new market awareness, and funding for investment. Solutions can be found through hiring management staff with specific knowledge of a target country´s culture and its language; and more effectively, where a partner can be identified in the market the company wants to do business. International networking is essential for all sizes of business, including small and medium-sized enterprises (SMEs).

References:

[1] Osterwalder, A. Pigneur, Y. 2009
[2] http://wealldesign.co.uk
[3] http://www.flourishingbusiness.org

CONCLUSIONS AND FUTURE PERSPECTIVES

CONCLUSIONS AND FUTURE PERSPECTIVES

The successful preservation of European historic cities depends on their capacity to survive as living cities. Appropriate sustainable energy management can improve the liveability and quality of life for their citizens and ensure the preservation of their social context. Energy and functional upgrading and adaptation of historic districts is a matter of sustainable management, and the EFFESUS project has significantly contributed to this challenge with the development of an inter-connecting system of solutions that provide mechanisms for balancing conservation and sustainability in the context of a changing climatic, socio-economic and cultural environment.

The EFFESUS project has brought together 23 partners and seven historic cities across Europe, working jointly for four years with a multiscale and transdisciplinary approach. As result, a new generation of methodologies, technologies and tools to support the adaptation of historic environments to modern requirements has been developed.

A Decision Support System comprising a methodology for evidence-based diagnosis and decision-making is one of the key results. This software tool is supported by multiscale 3D city models with the objective of assisting decision makers to select suitable sustainable strategies for historic districts. Within the project, the need for strategic information management has been worked out, balancing the data requirements with the accuracy of the results. Different levels of decision-making and different ways to introduce the information to the system to give an answer to different cities have been considered. This ensures that the strategy can be replicated in cities across and outside Europe and provide tools for public bodies to design new conservation policies and action plans.

Furthermore, EFFESUS has developed innovative solutions for the improvement of the energy performance of historic buildings and renewable energy supply in historic districts. SMEs and industrial partners participating in these developments have gained experience of relevance to the cultural heritage market and are able to contribute to professional training in the field. Working in cooperation with restorers, research partners and local administrations, and demonstrating innovative solutions in different sites, was crucial for the definition of new business models.

Thus facilitating the transformation of historic cities towards a new paradigm of a sustainable, resilient and cohesive smart historic city. The same principles of EFFESUS can be used in future research to broaden the scope from energy efficiency to climate change and hazards risks reduction.

ACKNOWLEDGMENT

This publication is based on the research results obtained by the EFFESUS project, which has received funding from the European Union's Seventh Framework Programme (FP7-2012 „Energy-efficient Buildings") under grant agreement No. 314678.
The EFFESUS team would like to thank the European Commission, Directorate General (DG) Research and Innovation, and particularly Project, Legal and Financial Officers who have supported the project during its four years of development: Adele Lydon, Anne-Helene Deltombre, Ekaterini Hambouri, Linda Rijckaert, Marie Yeroyanni and Michel Chapuis.
We would also like to express our gratitude to our External Experts Panel for their commitment and assistance, and the external reviewers for their constructive comments and inputs during the mid-term evaluation.
We are very thankful to stakeholders who made possible the installation of EFFESUS developments in the case studies and facilitated data collection: Bayerisches Landesamt für Denkmalpflege Munich, Beyoğlu Municipality (İstanbul), Budapest University of Technology and Economics, Consorcio de Santiago de Compostela, Fraunhofer-Zentrum für energetische Altbausanierung Benediktbeuern, Denkmalpflege Benediktbeuern, Glasgow City Council, Municipality of Genoa, Municipality of Gotland, and Yoker Housing Association (Glasgow).
Furthermore, a special thanks to the UNESCO Regional Bureau for Science and Culture in Europe, Venice, for the fruitful collaboration in organising the Winter School, and giving visibility to the projects' results to World Heritage Site managers; and to the i-SCOPE project, co-financed within the CIP ICT-PSP Programme of the European Commission, for providing access to the services which helped with the generation of the geometric model of Santiago de Compostela.
EFFESUS results were achieved through the contribution and cooperation of all partners, bringing together knowledge and skills in different fields to achieve the common objective. With their enthusiasm and patience they have paved the way to improving energy efficiency in historic districts.

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

EFFESUS PARTNERS

Tecnalia Research & Innovation, Spain
Isabel Rodriguez-Maribona (Overall Project Coordinator), Aitziber Egusquiza (Lead Work Package 5), Alessandra Gandini (Finanacial and Administrative Coordinator; Lead Work Package 10), Iñaki Prieto, José Luis Izkara, Leire Garmendia

tecnalia Inspiring Business

Fraunhofer Institute for Building Physics IBP - Germany
Gunnar Grün (Scientific Coordinator), Patrick Schumacher (Lead Work Package 3), Elena Köck, Juan Rodriguez Santiago, Britta von Rettberg, Claudia Schindler, Christine Milch, Ralf Kilian, Bernd Pfundstein, Ursula Gerhold, Christina Kuba

Fraunhofer IBP

Fraunhofer Center for International Management and Knowledge Economy MOEZ - Germany
Urban Kaiser (Lead Work Package 9) Uta Pollmer, Robin Bürger, Oliver Krahl, Erik Ackermann

Fraunhofer MOEZ

R.E.D. srl, Italy
Luc Pockelé, Sandro De Grandi, Giulia Mezzasalma

Integrated Information Systems (I2S), Greece
Kostas Seferis (Lead Work Package 6), Dionysia Michanou, Aris Georgoulis, Pavlos Kariotellis, Kostas Hirikakis, George Vovos, Dimitris Marfantas, Vasilis Elenis, Dimitris Sampanis

Snekkeriet Verdal AS, Norway
Atle Aune, Ellev Steinsli

SAMPAŞ Nanotechnology, Turkey
Eser Karakaya, Kader Özgür, Mehmet Mermutlu, Evrim Arslan
Pınar Çakır Hatır, Nurcan Eroğluer

D'Appolonia S.p.A., Italy
Serena Pagliula (Lead Work Package 2), Margherita Scotto

Consorcio de Santiago, Spain
Ángel Panero Pardo, Ramón Fernández Hermida, Lourdes Pérez Castro

ACCIONA Infrastructures S.A., Spain
María Casado Barrasa (Lead Work Package 7), Jaime Jose Cubillo Capuz
Patricia Maria Perez Tarancon

Uppsala University - Campus Gotland, Sweden
Tor Broström (Lead Work Package 1), Petra Eriksson, Anna Donarelli, Fredrik Berg, Gustaf Leijonhufvud

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

EURAC Research, Italy
Alexandra Troi, Elena Lucchi, Francesco Roberti, Luca Baglivo, Dagmar Exner, Guilia Garegnani, Laura Maturi, David Moser

Delap & Waller EcoCo Ltd., Ireland
Jay Stuart

Dennis Rodwell, United Kingdom of Great Britain and Northern Ireland
Dennis Rodwell

Italian National Research Council - Institute of Atmospheric Sciences and Climate, Italy
Adriana Bernardi, Francesca Becherini, Maria Di Tuccio, Arianna Vivarelli

University of Stuttgart - Materials Testing Institute (MPA), Germany
Jürgen Frick, Manuela Reichert, Michael Stegmaier, Thomas Popp, Oliver Mielich, Frank Lehmann, Helmut Ernst, Erich Schoun, Thomas Kasel, Martin Menke, Wolfgang Steiner, Markus Kohn, Mirjana Gudan, Axel Kaiserauer, Frank Bartels, Gert Seifert, Ingeborg Bathelt, Sebastian Dantz, Manfred Gottschalk, Mehdiye Panzehir, Ahmet Dogan Duran, Katja Herter, Laura Meier

Norwegian University of Science and Technology (NTNU), Norway
Eir Grytli, Daniel Bakonyi, Steinar Grynning, Arild Gustavsen, Sonja Jurosevic, Cezary Misiopecki, Jon Nordsteinen, Ihara Takeshi

Bofimex Bouwstoffen BV, The Netherlands
Bas Verhey, Harold Brocken

Historic Environment Scotland, United Kingdom of Great Britain and Northern Ireland

Carsten Hermann, Roger Curtis, Ewan Hyslop, Vanesa Gonzales, Catherine Carter

A. Proctor Group Ltd., United Kingdom of Great Britain and Northern Ireland

Iain Fairnington, Keira Proctor, Sue Menmuir, Pamela Howat, Jim McAskill (Factory Manager), Wilson Shaw (BCA Insulation), Alan Brydon (Garnett Controls Ltd), Ian Stewart (Stewart Energy)

HOR-BER Ltd., Hungary

Sára Hrabovszky-Horváth (Lead Work Package 8), Gergö Zsidek, Zsolt Horváth, Zsoltné Horváth, Tijana Dimitrijevic

SAS Gouas, France

Francis Gouas, Virginie Gouas, Patrice Alzon, Christiane Alzon, Jean-Claude Chasle, Kevin Gouas

Advanced Management Solutions, Greece

Constantinos Tsoutis, Maria Sachini, Panagiotis Skarvelis, Fotis Manesis

Active Aerogels, Portugal

Bruno Carvalho, Marta Ochoa

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

EXTERNAL EXPERT PANEL

NO.	ORGANISATION	COUNTRY/REGION	KEY PERSONNEL	FUNCTION
1	AEERPA	France	Marion Didieu	President of the European Association of Architectural Heritage Restoration Companies
2	Architects Council of Europe + Royal Institute of Architects of Ireland	Ireland	Selma Harrington	President 2010-2013; Architect, Lecturer, Sustainable Heritage Consultant
3	Genoa Municipality	Italy	Mirco Grassi	Director of Public Works
4	Getty Conservation Institute	USA	Shin Maekawa	International Expert in Energy Control Systems
5	Istanbul Municipality	Turkey	Ilhan Turan	Deputy Mayor of Beyoglu Municiplity
6	Monumentenwacht	The Netherlands	Jacques Akerboom	Director of Monumentenwacht Noord-Brabant
7	Riksantikvaren - Directorate Cultural Heritage	Norway	Terje Nypan	Consultant at Riksantikvaren. Chairman of the European Heritage Legal Forum (EHLF)
8	Specialisation Architectural Heritage Genoa	Italy	Stefano Musso	Director of the Specialisation School in restoration of Monuments
9	Hungarian Judicial Office	Hungary	Péter Aszalós	–
10	Urban Conservation Specialist	International	Francesco Siravo	Urban Planner, Historic Cities Support Programme Aga Khan
11	Visby Municipality	Sweden	Bertil Klintbom	Region Gotland
12	UNESCO Regional Bureau for Science and Culture in Europe, Venice	Italy	Davide Poletto	Project Officer
13	Architects' Council of Europe (ACE-CAE) E^2ARC	Belgium	Sara Van Rompaey	Board Member 2014-2015 Architect – Heritage Expert
14	World Monuments Fund	International	Lisa Ackerman	Executive Vice President and Chief Operating Officer

IMPRINT

Fraunhofer-Center for International Management and Knowledge Economy MOEZ
Städtisches Kaufhaus Leipzig
Neumarkt 9-19, 04109 Leipzig
Phone: +49 341 231039-150
Email: urban.kaiser@moez.fraunhofer.de
Internet: www.moez.fraunhofer.de

Editors
EFFESUS consortium
Editorial deadline: March 2016

Design and typesetting
Pfefferkorn & Friends
www.pfefferkornundfriends.de

Print
Weltbuch Verlag GmbH
www.weltbuch.com

Edition
300 copies
This brochure can be ordered from the publisher.
For more information about the project please visit
www.effesus.eu

The research leading to these results has received funding from European Union´s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 314678.

Fraunhofer-Center for International Management and Knowledge Economy MOEZ

Städtisches Kaufhaus Leipzig
Neumarkt 9-19
04109 Leipzig, Germany
Phone: +49 (0) 341 231039 – 150
E-Mail: urban.kaiser@moez.fraunhofer.de