Sustainable refurbishment of building facades and exterior walls

7th FP, Theme Environment (including Climate Change)
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Executive summary

SUSREF developed technologies and methodologies for sustainable refurbishment of external walls. SUSREF was based on the premise that 1) refurbishment of external walls is one of the most efficient ways of reducing environmental impacts of European building stock; 2) European building sector is facing huge needs of renovation; refurbishment of external walls is among the most urgent tasks; 3) Although there are technological solutions, the risks and optimal solutions are not fully understood; 4) External walls have an extensive effect on building performance and several aspects have to be taken into account when developing new concepts. 5) Urgent needs of refurbishment are not only faced in the EU but also in neighbouring areas; development of functional and environmentally efficient technologies would support the European industry to export projects and the neighbouring areas to adopt sustainable technologies.

The objective of the project was to 1) identify the needs to refurbish building envelops in the EU to understand the significance in terms of environmental and economic impacts; 2) develop a systemized method to manage the functional performance of solutions; 3) develop sustainable product concepts; 4) disseminate results for building industry, standardisation bodies, and policy-makers in terms of technological knowledge, guidelines and recommendations.

SUSREF assessed the potential savings in energy and costs with help of using scenarios for the refurbishment of external walls. The total investment cost was assessed to be 28000 million euro/year directed for the energy related refurbishment. On the other hand the savings in energy costs were assessed to be 2500 million euro/year. The difference in annual Life Cycle Cost is in average -11 000 million euro within 20 years. In addition, it was assessed that the corresponding increase of labour would be 396000 man years/year. The estimated potential CO_2 savings is 72 Mt/y.

It was defined that the overall sustainability of the developed concepts and technological solutions of the project has to be assessed considering the following aspects: 1) Durability, 2) Impact on energy demand for heating, 3) Impact on energy demand for cooling, 4) Impact on renewable energy use potential, 5) Impact on daylight, 6) Environmental impact of manufacture and maintenance, 7) Indoor air quality and acoustics, 8) Structural stability, 9) Fire safety, 10) Aesthetic quality, 11) Effect on cultural heritage, 12) Life cycle costs, 13) Need for care and maintenance, 14) Disturbance to the tenants and to the site, 15) Buildability.

The usability of the approach requires the definition of assessment methods for different aspects. Time and labour consuming methods are not always needed for all aspects but some aspects can be assessed with help of expert assessment. The defined methods for durability, energy performance, environmental impacts and life cycle costs are simulation and calculation methods. The building physical assessment has an important role in the overall technical assessment of the suitability of refurbishment concepts. It ensures the physical performance and durability of the structures while the energy and material use related environmental effects are minimised.

Both generic refurbishment concepts and company specific solutions were developed. The project studied the following general refurbishment cases: 1) External insulation, 2) Internal insulation, 3) Cavity wall insulation, 4) Replacement Insulation during renovation. The SME partners of the project developed 15 refurbishment concepts. All concepts were systematically assessed with help of the method. The following information was developed for the concepts: Cross section figures of the existing wall, Cross section figures of the refurbishment solution, Material layers and thicknesses, Working methods, Areas of suitable application, Known problems related to refurbishment method, and Market potential.

SUSREF also studied and summarised relevant standards and regulations for sustainable refurbishments, which might need revision, and created recommendations for standardisation bodies and policy makers.

Summary description of the project context and the main objectives

The starting point of the SUSREF project was as follows:

1) The Refurbishment of the external walls of any building is one of the most efficient ways of improving the environmental impacts of the European building stock.
2) The age of the build structure in the European building stock is causing a situation where the building sector and building owners are facing the extensive challenge of refurbishing many of the buildings. The renovation and refurbishment of the building facades and external walls are among the most urgent tasks to be undertaken.
3) Although there are technological solutions for refurbishment of external walls, the risks and optimal solutions of the new concepts are not fully understood. In order to avoid creating early problems in the energy renovation of buildings, the new concepts and solutions cannot be used without achieving a comprehensive understanding about the building/s physical behaviour, the products and the optimal solutions with regard to energy efficiency and environmental impacts.
4) External walls have an extensive effect on building performance and several aspects have to be taken into account when developing new concepts for refurbishment. An optimal approach should consider the following aspects: a) effect on energy consumption, b) building physical behaviour and durability, c) good integration with building structure, details and building services, d) effect on indoor environment and comfort, e) aesthetics.
5) The urgent need of good building refurbishment methods are not only faced in the EU but also - even more greatly - in neighbouring areas and other parts of the world. The development of functional and environmentally efficient technologies and concepts would support the European industry in exporting technology and projects, and to support and advise the neighbouring areas to adopt more sustainable technologies.

The optimal solutions for the stated problems vary in Europe, because of the difference in age, and structure of the building stock, many various building technologies have been applied, there are various cultural-historic values of buildings, different climatic conditions at present and different foreseen climatic changes (because of global warming) and related risks. This is why the optimal solutions for sustainable refurbishment of buildings vary across Europe. On the other hand, Europe benefits from the development of a common approach and making cross border efforts for environmental innovations and export. The theory of building physical behaviour regarding external walls, and the principal effect of external walls on building performance and energy efficiency is common, although the relevant and optimal solutions differ.

This project aimed at creating the following outputs:

- inform building industry about the optimal sustainable technologies available and potential of these technologies
- guide and inform standardisation bodies about the comprehensive sustainability performance of building external walls, giving recommendations on how this should be considered in the further development of CPD related product specifications and sustainable building standardisation
- inform policy makers about the overall significance of building external walls in the progression of the European building stock towards sustainable performance.

The main objectives of the SUSREF project were:

1) to identify and understand the volume of need to refurbish the building envelops in the EU and in neighbouring areas. To understand the meaning of these needs in the first place in terms of environmental impacts and secondly in terms of economic impact and business potential;
2) to develop a systemized theory and differing technologies when refurbishing building facades

and external walls in order to ensure the functional excellence of solutions. To analyse technologies from the view point of building physics, comfort and energy efficiency. To consider the various challenges in different parts of Europe in terms of present climate and foreseen risks of changes, technological differences, and cultural-historic differences. And finally to deliver sets of relevant performance specifications for sustainable refurbishment;

3) to develop systemized methods for consideration of environmental performance of external walls. To assess and ensure the sustainability of the developed technologies in terms of environmental impacts, life cycle costs, social and cultural impacts;
4) to develop sustainable concepts for carrying out refurbishments projects;
5) to disseminate the results for a) building industry, b) standardisation bodies, and c) policy-makers and authorities in terms of technological knowledge, guidelines and recommendations.

Sustainable construction technologies have a great potential with regard to overall environmental effects. The building sector is responsible for approximately 40% of Europe's total primary energy consumption. The main energy and CO2 saving potential of building and construction lies in the existing building stock and in building envelopes. The SUSREF project developed system-based solutions for the refurbishment of external walls, and optimised results in terms of building performance and sustainability.

The baseline for the study was as follows.

The existing methodologies and knowledge on which the project was based include the following:

1) Modelling of solutions for the refurbishment of façades and external walls
   This forms the basis for the analysis and development of a range of solutions with reference to energy efficiency, building physical performance and impacts on the indoor environment, constructional complexity, building services integration, LCC and environmental impacts.

2) Technological solutions developed for the refurbishment of facades
   This forms the basis for the involved industrial partners to further develop functional and environmentally efficient solutions.

3) Life cycle assessment methods
   These methods are necessary in order to compare and show the environmental and life-cycle economical characteristics of the alternative technologies.

4) Knowledge management methods and tools for optimisation
   Sustainable refurbishment is a knowledge-intensive process. Thus tools are needed in order to enable the comparison and optimisation of alternative refurbishment measures and the timing of these measures.

5) Building physical and energy models
   It is necessary to use this kind of modelling to be able to assess alternative solutions, this enables the development and selection of functionally qualified and energy-efficient solutions.

Realized refurbishment projects tend to be individual solutions or pilot projects that are rarely repeated thus relatively expensive. This also means that there is little continuous development and possibility of learning from earlier experiences and applying good practice and solutions considering the local circumstances and requirements.

There have been attempts to model refurbishment solutions. The project made use of these existing models and further develop those in order to better suit for the wider comprehensive target of the project. The project made use of the existing and advanced technological solutions, and analysed, modelled, improved and developed concepts so that selection can be done considering the regional and localised climatic conditions, ensuring good functionality and optimising the energy and environmental efficiency.

LCA is a technique for assessing the environmental aspects and potential impacts with a product by compiling an inventory of relevant inputs and outputs of a product system, evaluating the potential environmental impacts associated with those inputs and outputs and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study. General guidelines are given in ISO standards 14040 and 14044 and in the International Life Cycle System Handbook. Rules for the environmental declaration of building products are given in ISO 21930. Life cycle costing (LCC) is a technique for estimating the cost of whole buildings, systems and/or building components and materials, and for monitoring the occurred cots and impacts throughout the building life. The technique can assist decision-making in building investment projects. LCC is used to evaluate the cost performance of a building throughout its lifecycle, including acquisition, development, operation, management, repair, disposal, and decommissioning. In addition to internationally agreed standards and guidelines, there are a number of national and specific methodologies for integrated life-cycle management of buildings. SUSREF applied the existing life cycle assessment methods for the assessment of refurbishment concepts.

Building physical models have been developed for the analysis and assessment of building physical behaviour and energy performance. These are assessment and simulation models that cover moisture dynamics in building envelopes, computational simulation of heat, air and moisture transport in materials and constructions and the hygrothermal interaction between the materials of building envelope and surrounding climate. These models enable assessment of a layout in respect to e.g. effects on indoor air, moisture buffering, air flow patterns near surface and risk of mould growth. Some of the tools concentrate on single building components, as building envelope (MATCH), and others on the whole building performance (WUFI+). Many of the common models, however, concern only heat transfer problems and are multidimensional tools for analysing thermal bridges (HEAT2). Also on the building level, the simulation of energy performance is dominating (EnergyPlus). The purpose of these models is to support the achievement of energy efficient and durable constructions and good indoor air quality.

SUSREF applied relevant building physical models and developed guidelines for the building physical assessment of the refurbishment concepts of exterior walls.

The aim of the project was also to study and summarise relevant standards for sustainable renovations that might need revision and recommendations for standardisation bodies. Relevant standards are in the fields of

- environmental assessment of building products and buildings,
- life cycle costing,
- service life assessment.

Euro codes are European-wide standardized calculation rules for Building industry. SUSREF also discussed and made recommendations for the development of a new Euro code which takes into account refurbishment aspects of building envelope and frame.

The CE marking is based on a harmonised product standard (hEN) or a European Technical Approval (ETA). The European Technical Approval granted only by a member body of the European Organisation for the Technical Approvals, EOTA. The building materials which used in renovation and refurbishment are CE-marked now according to the same rules as the products used in new constructions. For the harmonized standards to be relevant for refurbishment work, it would be necessary that the “intended use” of the product includes refurbishment and that all relevant material properties are declared.

The product-related requirements are described in the relevant technical product standard and for renovation and refurbishment products there are no individual separate technical standards exists. Products used in renovation and refurbishment should fulfil the same requirements that products used in new construction. On the other hand new materials and product concepts will be developed with new properties for the renovation and refurbishment market. New, technical standards and test methods may be necessary to accommodate to these new products. For these cases the building material industry needs to take the standardization initiative towards to the members of CEN committee who then launches the preparation work for new standard. The process for new standards already exists and even this is quite long lasting procedure there is no need for new working method (standard procedure) for renovation materials use.

The ETA Guideline (ETAG) is a basis for ETA's, i.e. a basis for technical assessment of the fitness for use of a product for an intended use. An ETAG is not itself a technical specification in the sense of the Construction Product Regulation, but commonly ETAG guideline exists prior to European Technical Approval for the relevant product. ETAG comprise a list of the relevant Interpretative Documents, the specific requirements for the products within the meaning of the Essential Requirements, the test procedures and the methods of assessing and judging the results of the tests, the procedures related to the Attestation of Conformity and also the period of validity of the approval. It may be important to set up ETAG guidelines for renovation materials and concepts.

In the transformation of buildings to sustainability, governmental authorities may play different roles:

- As a governor through the launch of control and regulatory instruments.
- As developer including ”green procurement” specifications in housing developments and public buildings.
- Acting as a demonstrator or "early adopter" of new solutions demonstrating the validity and viability of new solutions in pilot buildings or their own property buildings
- Acting as a “mobilizer” of the sector, promoting the implementation of concepts or solutions through economic & market based instruments rewarding, incentivizing, and introducing direct subsidies.

The recast directive on energy performance of buildings forms a strong basis for the regulation and steering of energy performance of existing buildings and building renovations. In July 2012 all Member States should have adopted and published the laws, regulations and administrative provisions necessary to comply with Articles 2 to 18, and with Articles 20 and 27. These include the requirement to take the necessary measures to ensure that when buildings undergo major renovation, the energy performance of the building or the renovated part thereof is upgraded in order to meet minimum energy performance requirements set so far as this is technically, functionally and economically feasible. In addition, the energy performance certificate will include recommendations for the cost-optimal or cost-effective improvement of the energy performance of a building or building unit. The recommendations included in the energy performance certificate shall cover measures carried out in connection with a major renovation of the building envelope.

The fragmented structure of the building sector and the huge spectrum of technical solutions and technical quality of existing buildings and building envelops means a big challenge for the successful implementation of the extensive refurbishment of exterior walls of the European building stock.

In addition to the coming legislation and regulations that will be based on the recast energy performance directive, there is also a need to develop other instruments than control and regulatory instruments. Especially fiscal instruments and incentives and informative support will be needed in order to

- to achieve common willingness among public to make efforts for significantly improved quality and energy performance of exterior walls of buildings
- to avoid risks in the connection of building renovations
- to economically facilitate choices that are excellent from the view point of technical and long-term sustainability reasons.

Main S & T results

SUSREF developed

- information about the significance of the refurbishment of exterior walls of the European building stock. The significance was assessed in terms of potential energy savings, CO2 savings, life cycle costs and labour.
- a systemized approach for the assessment and development of refurbishment concepts for exterior walls. This approach includes assessment criteria and detailed guidelines for assessment methods.
- general and specific refurbishment concepts and their assessment results
- guidelines for refurbishment projects and building industry
- recommendations for standardisation bodies and policy makers.

This report summarises the main S&T results of the project.

Significance of the refurbishment of exterior walls

The total wall areas of the European residential building stock were summarised based on earlier research data (IMPRO 2008). The estimated façade areas are 12600 million m^2 for single family houses and 4450 million m^2 for multifamily and high rise buildings. The potential of the refurbishment of exterior walls was assessed in terms of estimated savings in energy use, GHG emissions, life cycle costs and labour. The assumed maximal potential of SUSREF concepts in Europe was as follows:

- Adding new/more insulation will be relevant for 40–60% of the building stock during 10 years depending on building age and climate zone
- Stone walls are not usually be insulated outside but in the case of an extensive renovation.
- Demolition of 5% of the present building stock will take place during the next 10 years.
- Increase of 7% of present building stock will take place during the next 10 years.
- The walls already insulated or replaced by new ones have not been included to the volumes of potential refurbishments. Some energy saving actions will be done also for those during the next 10 years but the relative importance of those actions is small.
- For a certain number of buildings there are either no possibilities or needs to make external changes (25–50% of the building stock built before 1945 (because of aesthetic and cultural reasons) and 20–40% of the building stock built after 1970 (because the walls are in good condition).
- When calculating walls to be refurbished life-cycle optimized comprehensive concept was preferred instead of separate actions.

The following estimates were chosen to represent the potential of SUSREF Concepts during the coming 10 years:

New inner insulation	10% of total external wall areas in Europe (without cavity walls).
External insulation	20% of those external walls that in principle can be provided with an external added insulation in Europe (without cavity walls). The starting point was that there is a big part of old buildings that cannot be externally insulated because of cultural and aesthetic reasons. The starting point was also that the external insulation of those relatively new walls that are in very good condition will not be externally insulated during the coming ten years.
Cavity insulation	25% of total cavity wall areas in Europe which have not yet been insulated.
Replacing renovation	25% of the residential building stock (without cavity walls).

The assessed volumes of refurbishment are bigger than what has been the case during the last 10 years. The explanation for this choice is that it was thought that the different new steering mechanisms will accelerate the building refurbishment projects. The project assessed the potential effects of the refurbishment of exterior walls in terms of GHG emissions, costs and labour. The result was assessed with the help of the description of refurbishment concepts and scenarios for the realization of refurbishments. The total investment cost was assessed to be 28000 million euro/year directed for the energy related refurbishment. The savings in energy costs were assessed to be 2500 million euro/year. The difference in annual Life Cycle Cost is in average -11 000 million euro within 20 years. In addition, it was assessed that the corresponding increase of labour would be 396000 man years/year. The estimated GHG saving was 72 Mt/y.

Systematic approach for the assessment of refurbishment concepts

The starting point of the project was that a systematic approach is needed especially for SMEs when they start to improve refurbishment concepts and develop new concepts. It was further defined that it is important to develop a method with help of which it is possible to deal with different aspects of refurbishment concepts. Important aspects include not only the aspects of technical and functional performance but also process related aspects and life cycle aspects. The process related aspects should not be limited to technical feasibility but also consider the impacts caused to neighbouring buildings and their users. The life cycle aspects should cover both environmental as well as financial aspects. It is important that the developer of a refurbishment product concept is able to iterate and optimize the solution ensuring that a certain level of building performance is achieved while minimising life cycle impacts. A systematic approach for the development of refurbishment concepts for exterior walls is important in order to enable comparisons of different refurbishment concepts, and for iterating and optimizing between alternative solutions, setting targets for the refurbishment exterior walls, avoidance of risks and consideration of the whole building context and neighbouring environment.

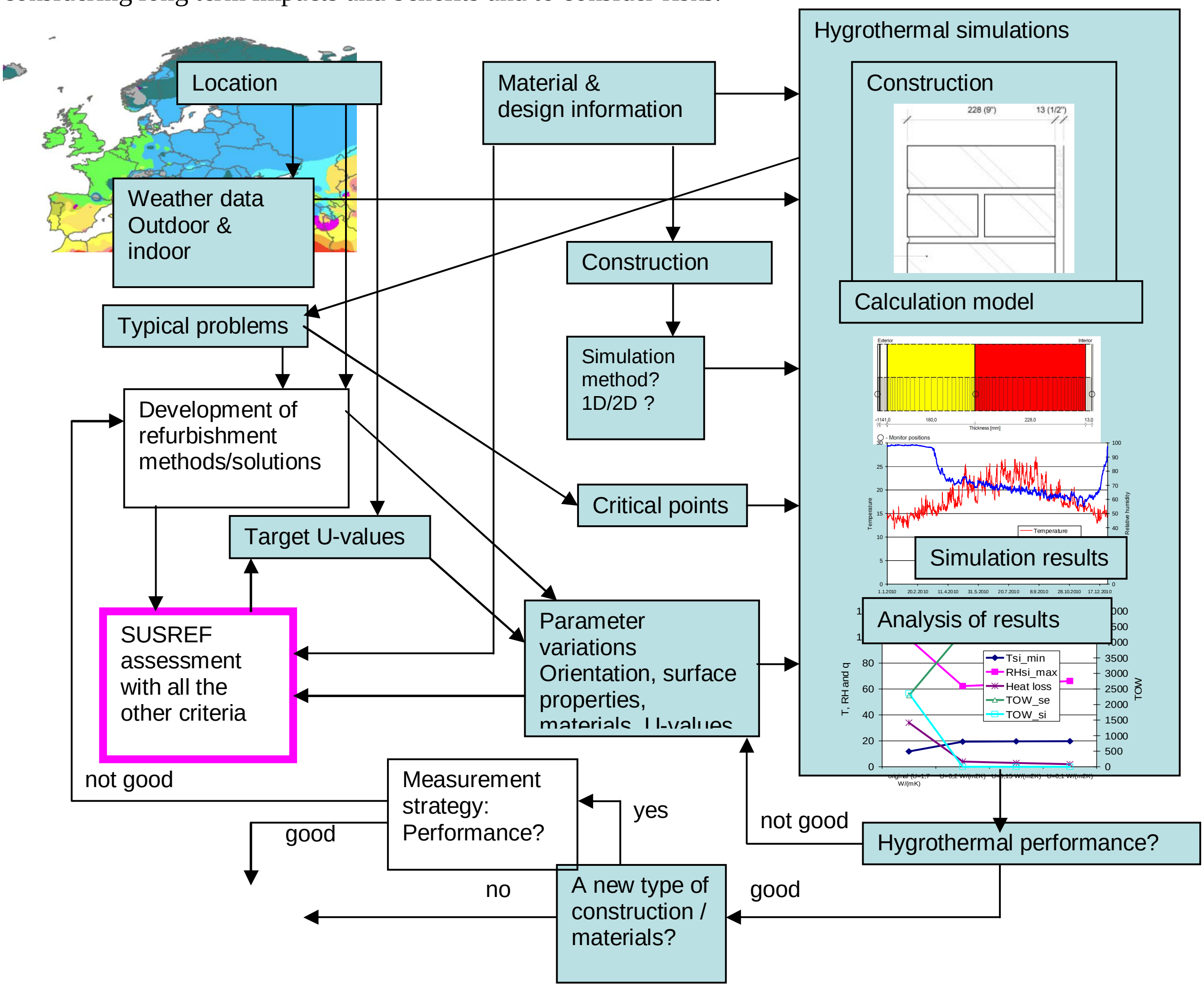
The following list shows the final sustainability assessment criteria defined by the SUSREF project. These criteria together with the related assessment methods define the systematic approach for the sustainability assessment of refurbishment concepts of exterior walls. On the basis of the discussion it was defined that the overall sustainability of the developed concepts and technological solutions of the project will be assessed considering the following 15 aspects:

1) Durability
2) Impact on energy demand for heating
3) Impact on energy demand for cooling
4) Impact on renewable energy use potential
5) Impact on daylight
6) Environmental impact of manufacture and maintenance
7) Indoor air quality and acoustics
8) Structural stability
9) Fire safety
10) Aesthetic quality
11) Effect on cultural heritage
12) Life cycle costs
13) Need for care and maintenance
14) Disturbance to the tenants and to the site
15) Buildability

Although the importance of different aspects vary with practical circumstances and with the desires and requirements of clients, the consideration of all aspects is important. Some of the aspects should be studied quantitatively in order to give an adequate understanding about the impacts. These aspects are Durability, Impact on energy demand, Environmental impact and Life Cycle costs. The list also covers important aspects related to construction and operational processes (Disturbance, Buildability and Need for care and maintenance). The list covers the most important functional performance aspects of exterior walls (Structural stability, Fire safety, Aesthetic quality, impact on Indoor environment). The usability of the approach requires the definition of assessment methods for different aspects. The recommended assessment methods are carefully described in SUSREF deliverables. The defined methods for durability, energy performance, environmental impacts and life cycle costs are simulation and calculation methods.

According to SUSREF conclusions the building physical development process can be seen as an iteration process where the best solution for any actual case is found by optimising 1)thermal performance of the envelope: reduction of the heat losses through the envelope, minimising thermal bridges, 2) moisture performance of the envelope: ensuring drying capacity, avoiding condensation, 3) durability of the constructions: reduction of the risk for mould, decay, frost and corrosion, 4) indoor air quality and comfort: thermal symmetry, no draft, control of humidity. Dynamic simulations with hygrothermal simulation tools are an important part of the assessment work. Depending on the construction type and refurbishment method to be analysed, the most suitable calculation and simulation tools should be chosen. One-dimensional (1D) coupled heat and moisture calculations tools are the best choice for constructions and solutions consisting of just homogenous layers. Ventilated cavities can be studied simplified with these tools, too. Two-dimensional (2D) coupled heat and moisture calculations tools should be used for constructions containing inhomogeneous layers, e.g. stone walls, fastenings, and ventilation cavities. Generally, 1D-tools are sufficient for most of the analysis with skilled expert use. The computation of coupled heat and moisture transport in two dimensions is usually time-consuming and the detailed information from a 2D or even 3D calculation may be overruled by other uncertainties.

The recommended assessment methods for environmental and financial impacts are life cycle methods. With regard to safety, indoor environment, aesthetic quality and process related aspects the method classifies essential issues and thus supports the developer of the refurbishment concept to assess the feasibility and quality of the concept. During the SUSREF project the systematic approach and the analyses were especially made use of in order to ensure good building physical behaviour, to address risks for low drying capacity or condensation, to define an adequate thickness and right quality of insulation materials regarding energy, carbon footprint and life cycle costs. The method especially supported the developers of concepts to select insulation materials and layer thicknesses considering long term impacts and benefits and to consider risks.



Flowchart presentation of the hygrothermal analysis of exterior wall construction as recommended by SUSREF

General refurbishment concepts

SUSREF developed both general and specific refurbishment concepts for exterior walls. The study combined different refurbishment technologies into four main groups. The technologies differ from each other mainly by the manner in how placement of new insulation layers would be normally undertaken. The primary technologies for refurbishing external wall are:

- Technologies for replacing existing walls (R)
- Technologies for applying external (insulation) layers (E)
- Technologies for inserting (insulation) materials in cavities in existing walls (C)
- Technologies for applying internal insulation (I).

The overall results are presented in Deliverable D4.2 and in SUSREF Final report Par B – General refurbishment concepts. The concepts were assessed from the view point of the selected 15 criteria as explained in the section “Systematic approach for the assessment of refurbishment concepts”. The following buildings types are covered in the development and assessment of the generic concepts

A. Small houses
B. Terraced houses
C. Multi-storey Apartments/Flats.

The original wall types considered in the assessment of the generic refurbishment concepts are as follows:

- Solid wall (brick, natural stone)
- Sandwich element (concrete panel + concrete panel)
- Load bearing wood structure (wooden frame)
- Insulated load bearing cavity (concrete block + concrete block)
- Load bearing cavity without insulation (brick + concrete block)
- Load bearing wood structure (wooden frame)
- Non-load bearing cavity (hollow brick + perforated brick)
- Non-load bearing concrete block without insulation (hollow brick + concrete block).

The generic concepts were assessed analytically and when relevant, using a parametric approach. This means that each performance aspect of the generic concepts will be assessed by dealing with relevant issues as parameters. Relevant issues are very much determined by specific performance aspects, and these could be different in many issues. Relevant issues may be for example be Quality and performance properties of materials, Thickness of insulation and other layers, Existence of air cavity, Fixing mechanisms, Quality of surface material, Condition of the existing structure, and Rainfalls and temperatures.

The results are summarised in the following regarding the aspects of durability and life cycle impacts. All assessment results are presented in SUSREF deliverable D4.2 General Refurbishment Concepts and summarized in Final Report B available on the SUSREF web page (http://cic.vtt.fi/susref/).

Building physical assessment and Durability

The main principle of designing and constructing wall structures is that the wall must be airtight and the water vapour permeability of structural layers increases gradually towards the outside surface of a wall. A water vapour barrier may be needed near the inner surface of a wall, if the water vapour permeability of materials is too high and the materials can’t absorb all the extra moisture or the moisture levels inside the wall may become too high. Rain water leakages into wall structures through defected joints and construction faults are harmful. If the insulation material is foam plastic or other water vapour tight material or if the insulation material is such that can absorb very little moisture, water leakages are especially harmful. The leaked water causes the biggest problems with mineral wool insulated timber frame walls. Excessive moisture levels may cause mould or rotting of timber parts.

When adding retrofit insulation and a new outer layer on the outer surface of an existing wall it acts like a sweater and a raincoat. Existing wall will become warmer and dryer. There is no critical limit of thermal insulation thickness, the thicker the better. If the new outer layer is water vapour tight, a ventilated air gap between retrofit insulation and the new outer layer is needed to remove moisture from the structure. For some reasons the old outer layer and possibly the thermal insulation may need to be replaced with new ones. The same principles mentioned above apply also in this case.

When adding retrofit insulation in a wall cavity it must be taken care of that there will not be any empty spaces. Sprayed PUR foam may expand so intensively while hardening that the pressure will break the wall. There are some foam types that stay soft after hardening and by using those, the risk of wall breakage is smaller. The bindings in between an inner and outer layer reduce the effectiveness of added thermal insulation.

When adding retrofit insulation on inner surface of a wall it must be ensured that there will not be water vapour tight layers in the existing wall. Otherwise there will be condensation risk in the existing wall. Typically there are intermediate floors and separating walls that make it impossible to add retrofit insulation on whole inner surface of a wall. The junction of these and the exterior wall are already cold and they will become even colder when adding retrofit insulation on the inner surface of the wall. This may cause condensation on wall junctions. The condensation risk increases if thermal insulation thickness increases, outdoor temperature decreases or indoor air humidity increases. The wall structures and their thermal insulation level affect to the condensation risk as well. The effectiveness of retrofit insulation is not as good on inner surface of a wall as on outer surface, because on inner surface there are cold bridges, which cannot be insulated.

There are some principals that help the design for good durability:

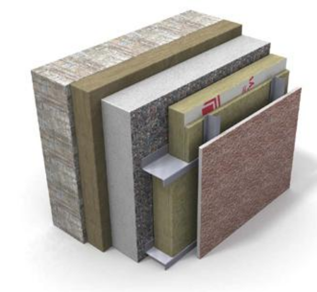
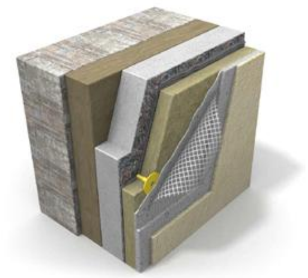
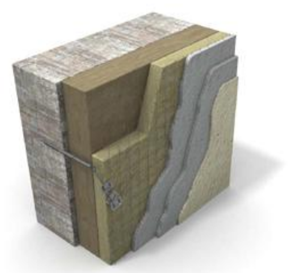
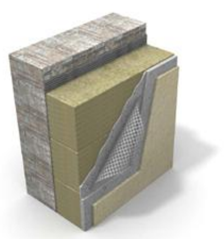
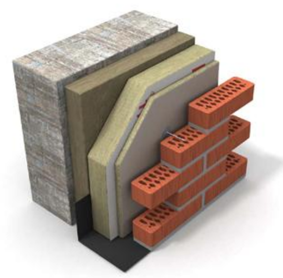
- ensure that walls and their joints are airtight and the water vapour permeability of structural layers increases gradually towards the outside surface of a wall
- it is more effective to add retrofit insulation on the outer surface of a wall and the risks of moisture condensation and accumulation in the existing wall are lower
- the thicker retrofit insulation on the exterior surface of a wall the better
- the thicker retrofit insulation on the inner surface of a wall the worse
- use materials and structures that are known to be durable
- ensure, that the old wall can hold the extra weight of retrofit part and if not, add extra bindings and fixings to the old wall
- design the structure and it's joints, sealings and supports carefully
- prevent driven rain water to flow into a wall structure and especially to the warmer side of a cellular plastic thermal insulation
- ensure the water tightness of joints between window, wall and external window sill
- control manufacturing and installation
- make inspections periodically
- repair found defects in time

The following Tables show refurbishment methods of different wall types and possible problems of that may occur and what should be taken in account to avoid possible problems. The tables are examples and the existing wall structures should be checked in every case with actual material properties and thicknesses with the climatic data of the building location.

If the one dimensional simulations show that there will be moisture problems with refurbished walls then it is very probable that there will be problems. If the simulations show that the refurbished wall structures will not have too high moisture content or moisture accumulation, this does not mean that there will not be problems after refurbishment. There are uncertainties such as material properties used in simulations and construction faults such as holes in water vapour barrier, air leakages, water leakages and air gaps between material layers.

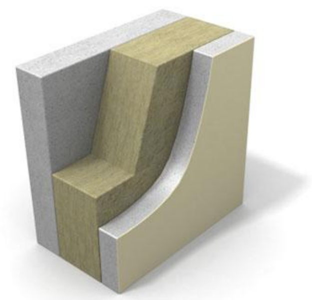
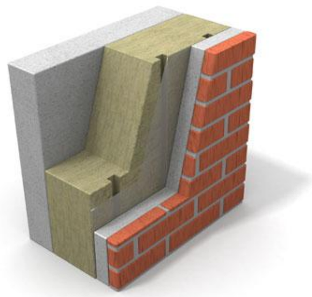
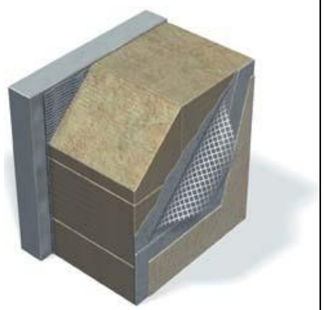
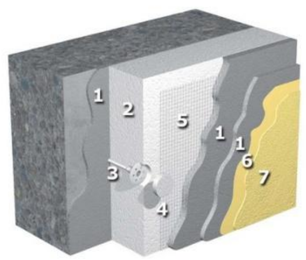
Different refurbishment methods of concrete sandwich elements and their moisture risks. Extra insulation is installed on old outer layer or on old insulation (Photos from Paroc Oy).

Refurbished wall	Description	Possible problems	Check following

	- Extra insulation on old wall - wind shield mineral wool - ventilated air gap - façade board	- rain water penetration behind facade board - frost damages of surface board - moisture condensation in air gap	- frost resistance of board - ventilation of air gap - water tightness of joints
	- Extra insulation on old exterior surface - render with float and set	- rain water penetration through joints and cracks of rendering - frost damages of rendering - moisture condensation behind rendering	- frost resistance of rendering - expansion joints
	- Outer layer removed - Extra insulation on old insulation - render with float and set	- rain water penetration through joints and cracks of rendering - frost damages of bricks - moisture condensation behind rendering	- frost resistance of rendering - expansion joints
	- Outer layer and old thermal insulation removed - New insulation (mineral wool or plastic foam) installed - render with float and set	- rain water penetration through joints and cracks of rendering - frost damages of bricks - moisture condensation behind rendering	- frost resistance of rendering - expansion joints
	- Outer layer removed - Extra insulation on old insulation - wind shield mineral wool - ventilated air gap - brick wall	- rain water penetration behind brick wall - frost damages of bricks - moisture condensation behind brick wall	- frost resistance of bricks - ventilation of air gap - support of brick wall - rain water penetration through brick wall

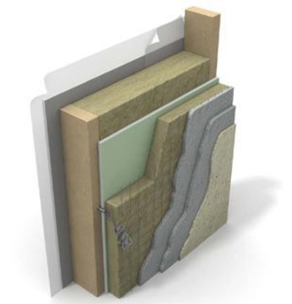
Different refurbishment methods of massive brick or aerated concrete wall and their moisture risks. (Photos from Paroc Oy and Weber).

Refurbished wall	**Description**	**Possible problems**	**Check following**

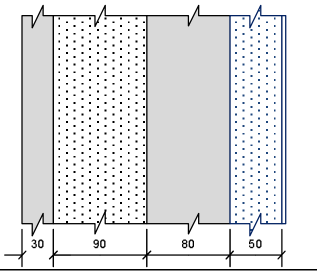
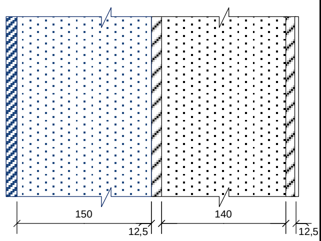
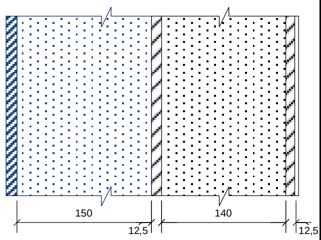
	- mineral wool insulation on old external surface - concrete outer layer	- rain water and inside air moisture penetration behind new outer layer - frost damages of concrete layer	- water tightness of joints - air and water vapour permeability of an old wall - frost resistance of new outer layer - need for ventilation
	- mineral wool insulation on old external surface - concrete outer layer with brick or ceramic tiles	- frost damages of concrete, bricks or ceramic tiles - condensed water vapour accumulation between thermal insulation and outer layer	- water vapour permeability of materials - water tightness of joints - need for ventilation
	- mineral wool insulation on old exterior surface - render with float and set	- rain water penetration through mortar - frost damages of mortar - condensed water vapour accumulation in mortar layer	- water vapour permeability of materials - expansion joints
	- mineral wool insulation on old exterior surface - wind shield material - ventilated air gap - façade board	- rain water penetration behind facade board - frost damages of surface board - moisture condensation in air gap	- water vapour permeability of materials - ventilation of air gap - outer layer thermal expansion and joints
	- cellular plastic insulation on old outer layer - render with float and set	- frost damages of mortar - condensed water vapour accumulation in cellular plastic or between old wall and cellular plastic	- water vapour permeability of materials - expansion joints

Refurbishment method of timber frame walls and their moisture risks. (Photos from Paroc Oy).

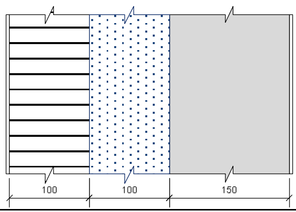
Refurbished wall	**Description**	**Possible problems**	**Check following**

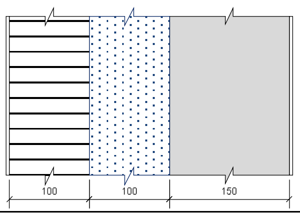
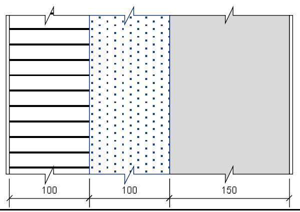
	- Outer layer possibly removed - mineral wool insulation on outer surface - render with float and set	- rain water and inside air moisture penetration behind surface layer - frost damages of concrete layer	- water tightness of joints - water vapour permeability of materials - expansion joints

Different refurbishment methods on inner surface of walls and their moisture risks.

Refurbished wall	Description	Possible problems	Check following
	- EPS or PUR foam on inner surface of a wall - gypsum board	- partition walls and floors are thermal bridges and they reduce the effectiveness of retrofit insulation - condensation on inner surface of old wall	- contact between thermal insulation and old inner surface - air tight sealing of insulating board edges and old structures
	- Mineral wool - gypsum board <THIS TYPE REFURBISMENT IS NOT RECOMMEND>	- partition walls and floors are thermal bridges and they reduce the effectiveness of retrofit insulation - condensation on inner surface of old wall on old water vapour barrier - high risk of moisture problems	- air tight sealing of insulating board edges and old structures - water vapour barrier in an old wall forms a condensation risk
	- EPS or PUR foam on inner surface of a wall - gypsum board	- partition walls and floors are thermal bridges and they reduce the effectiveness of retrofit insulation - condensation on inner surface of old wall on old water vapour barrier - high risk of moisture problems	- contact between thermal insulation and old inner surface - air tight sealing of insulating board edges and old structures - retrofit insulation must not be too thick

Different refurbishment methods for cavity walls and their moisture risks.

Refurbished wall	Description	Possible problems	Check following
	- EPS beads in the cavity	- settling of EPS beads - air leakages and moisture transfer because of air flow	- airtightness of inner outer layer - filling level of cavity

	- sprayed PUR foam in the cavity	- high expansion forces while foam is hardening	- airtightness of inner outer layer - expansion forces of PUR foam
	- blown mineral wool fibres in the cavity	- settling of mineral wool fibres - air leakages and moisture transfer because of air flow	- airtightness of inner outer layer - filling level of cavity

Different refurbishment concepts of building facades and external walls were analysed for possible long-term degradation. The analyses were conducted for the climate conditions of various European climates and with various outer core materials and thermal insulations. Degradation models used were as follows:

- Frost attack
  VTT simulation software assesses the occurrence and propagation of frost damage is evaluated based on the theory of critical degree of saturation developed by [Göran Fagerlund 1977]. Frost damage is assumed to take place when the moisture content of concrete exceeds the critical water saturation and the temperature descends below the freezing point at the same time.
- Carbonation and corrosion
  The model used to evaluate the rate of corrosion on the reinforcement includes an initiation period and a propagation period. Initiation of corrosion is assumed to take place when carbonation reaches the depth of reinforcement. Both the rate of carbonation and the rate of corrosion depend on the temperature and moisture content of concrete.
- Mould growth
  Numerical simulation of mould growth can be used as one of the hygrothermal performance criteria for the building structures. Mould is one of the first signs of too high moisture content of materials and it may affect the indoor air quality and also the appearance of the visible surfaces. Mould growth potential can be predicted by solving a numerical value, mould growth index, by using the dynamic temperature and relative humidity histories of the subjected material surfaces. The model was originally based on mould growth on wooden materials but has now been completed with several other building materials. The model can be used parallel with heat, air and moisture simulation models or as a post-processing tool.

Several refurbishment concepts were treated in European climates. The calculations were done so, that the whole service life of the original sandwich and a part of the service life of the refurbished wall were continuously monitored. As the combinations of variables - refurbishment concepts, insulation materials, concrete quality, coating materials, and climates – were so many, the calculations were done as case studies. The monitored degradation types were frost attack, carbonation and corrosion of reinforcement and mould growth; the mould growth index can be considered to serve as a general indicator of a moisture problem inside the wall. The general observations related to different refurbishment concepts were the following. The original (un-refurbished) sandwich wall was kept the same, however with two alternatives as the insulation material, mineral wool (MW) and expanded polystyrene (EPS). In the refurbished walls the additional thermal insulation was varied between mineral wool and polyurethane (PUR) i.e. in all case studies the both alternatives were considered.

- In Refurbishment Concept E1 – the additional insulation is laid on the original outer core of the sandwich and covered by a layer of rendering – the selection of thermal insulation material was not indifferent. PUR thermal insulation cannot be used if the thermal insulation of the original sandwich was of PUR or ESP. This is because the original concrete core is left between two layers of insulation water vapour diffusion coefficient of which is very low. The moisture which was left to the original concrete core cannot dry out in a reasonable time. That is why there is a great risk of mould growth and also a risk of continued corrosion in the reinforcement of the original concrete core. As a result of corrosion which can continue for decades there is a risk of collapse of the whole wall. If the original thermal insulation is of mineral wool and the additional insulation is of polyurethane, the mould and corrosion risks are much smaller as the moisture can evaporate towards the indoor environment. However, there is an intermittent risk period of about 10 years after the refurbishment when the mould growth may be high. The rapid increase of the mould risk is a result of higher temperature inside the wall and the rapid decrease of mould growth after the risk period is a result of relative humidity decreasing under the critical limit which is 85 %. Risk of frost attack exists in countries where the temperature goes below -5 oC. The risk of frost attack is increased when the rendering is let to be exposed to rain water and freezing immediately after manufacture – without sufficient hardening.

- In Refurbishment Concept E2 – mounting insulation boards (of MW or PUR) on top of the original sandwich and covering it with masonry panel boards leaving, however, a ventilation gap between the panel and the thermal insulation – the risks are similar to those of Concept E1. If the original thermal insulation is of mineral wool the risk of any moisture problem is moderate and temporary right after the refurbishment. However, if the original thermal isolation is of EPS and the additional thermal insulation is of PUR, there is a considerable and long lasting risk between the two thermal isolations. If the original outer core is left moist between the two layers of thermal insulation a prolonged corrosion of reinforcement in the original concrete core is possible. In long term that may risk the bearing capacity of the wall. The possible degradation of the masonry board was not considered in the analyses. However there may be a risk of frost attack in the board and a risk of corrosion in the frame work of the board. The framework of the panel boards is usually made of zinc coated steel plate which has a limited service life.
- In Refurbishment Concept R the original outer concrete core and the original thermal insulation are removed and replaced by a new thermal insulation and a layer of rendering on top the isolation board. The risks with this concept seem to be small with both options of thermal insulation. Frost attack is of course possible in cold climate countries. The reinforcing net in the rendering should always be of non-corroding or zinc coated steel otherwise corrosion of the steel net may cause premature deterioration of the rendering. The covering is made of masonry panels leaving a ventilation gap between the panel and the thermal insulation. Exclusive possible risks in the panelling boards there seem to be no other risk in the long-term performance of this refurbishment concept. Both options for thermal insulation can be used. Concept R seems to be relatively risk free. However, in cold weather countries the risk of frost attack should always be considered with concretes and mortars. Also the use of dense coatings on the original outer core or rendering may cause a long lasting mould risk.
- In Refurbishment Concept I an additional insulation layer is placed on the inner concrete core of the sandwich structure. There is a coating on the additional insulation layer. In the analysed case the original outer surface was provided with a coating for aesthetic reasons. The original thermal insulation is assumed to be mineral wool. There is no point to try to prolong the service life of the original concrete core if the limit state of the service life has already been reached at the time of refurbishment. The extending of service life is only reasonable by a coating if the carbonation has not reached the depth of reinforcement. The coating retards drying of the wall towards the outdoor air. On the other hand it prevents also the rain water to penetrate to the wall keeping it very dry at first. So, there is a period when the mould index is very low. However, if not reapplied in time the coating becomes more and more permeable with time letting more rain water to penetrate to the wall. Then the mould risk increases in the original thermal insulation. The risk is about the same with both thermal insulation options. If the original thermal insulation happens to be of ESP and the additional thermal insulation is of PUR, there is a danger of covering the inner concrete core between two dense thermal insulation layers. However, as the inner concrete core is normally at the time of refurbishment in a very dry state (RH < 85%), there should not be any mould or corrosion risk in this core. Careful planning is necessary to assure good performance of the refurbished sandwich walls. The original structure and its condition should be carefully studied because a successful planning is only possible when the materials and possible deterioration of the original sandwich wall is known. The risk of mould growth should be considered when using dense insulation material, such as ESP and PUR.

The typical cavity wall with external brick layer and the inner leaf build from concrete block was studied in combination with cavity wall insulation. The insulation was either sprayed polyurethane foam or blown mineral wool. Polystyrene beads are also used, but they were not studied in WUFI simulations because their material data was not available. The basic case, cavity without thermal insulation, was simulated as a reference. The cities were selected so that this structure is common in those cities. The results showed that adding thermal insulation into a wall cavity do not cause moisture problems. On the contrary adding thermal insulation even reduces the moisture levels in inner layer. The main reason for reduction of moisture level is better insulation of filled cavity, which increase the temperature of inner layer.

Environmental impact

Environmental impact assessment focuses on the impact of non-renewable energy (energy transmission through the wall and energy consumption of refurbishment materials), non-renewable raw materials (from energy production and refurbishment materials) and especially released greenhouse gases and thus carbon footprint. Main parameters which were used for the assessment of environmental impact and for different wall renovation concepts were:

- Material type (insulation, façade) and properties (specific weight, consumption, thermal conductivity, environmental impact)
- Existing wall type, deterioration rate and corresponding U-value
- Renovation concept and target U-value
- Building location and heating degree days
- Heating type and environmental impact from heating
- Material service lives and need for maintenance.

Energy renovation target level is dependent on building location and need for heating and cooling. Here the generic renovation concepts assessed according to the European climate regions: Nordic, Central- and Southern Europe and heating dealt as heat loss calculation through the wall.

Environmental impact in the connection of building renovations depends on the existing building type, building condition and renovation concept used. In typical building design, where the shape of building is square and rectangular, the exterior walls form 1.2 - 1.5 wall-m^2/one floor-m^2. Wall structures can be divided to light, medium and massive structures and when the used material amount is high, normally also environmental impact are higher compared to lightweight cases. The same principle is applicable also to renovation concepts; the lighter the structure is typically the smaller are the environmental impacts of the concept. At the same time, exterior walls are responsible for the heat transmission and thus have an effect to the total energy performance. Because of that, the impact from renovation materials should be studied alongside with the heat transmission and heating type. Depending on the existing building types, the additional insulation can be placed to the existing wall either externally, internally or into the wall cavity. This study focused mainly on the external and internal renovation cases because the material consumption remains small in the case of cavity walls and doesn't cause so significant effect in terms of energy saving and environmental impact. However, cavity walls are included when the renovation is performed internally or externally. The examples are given for chosen building types to illustrate the ability of energy saving building renovation and environmental impact.

Main findings related to the insulation thickness, insulation type, façade type and energy type used.

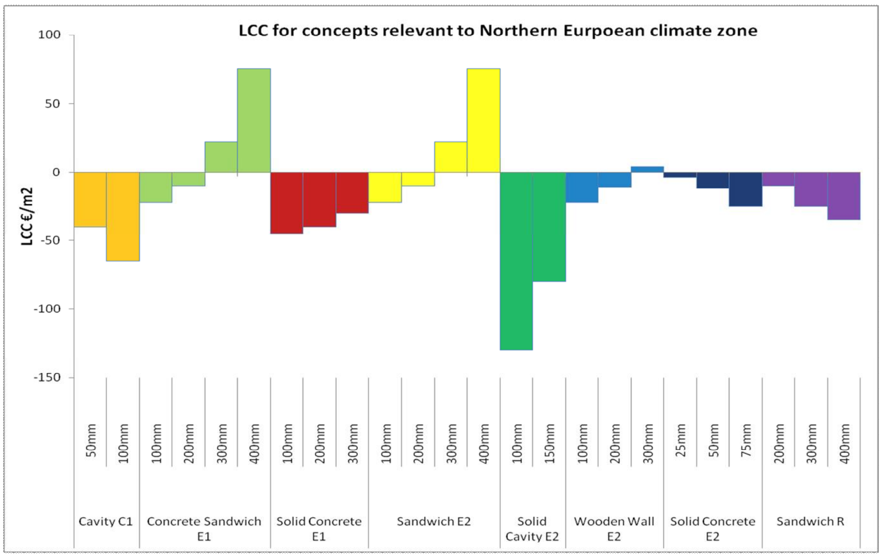
- Energy efficiency from specific insulation types depends on their thermal conductance. Insulation materials have a large range of variation in thermal conductance (varying at least between 0.07 – 0.44 W/m^{2}K) and in the case of 100 mm insulation this can cause an annual heat transmission of 8 – 50 kWh/m^2/a in Northern Europe. Correspondingly, insulation materials also have different specific weights which mean that the volume needed in wall renovation to achieve the same efficiency is different. On the other hand insulation materials are developed for certain conditions and with certain properties which makes the selection of right materials very important. Insulation material selection has significant impact not only to the energy and physical performance but also to the environmental impact.

- Expanded polystyrene, polyurethane, rock wool and lamb wool were studied. According to the results, PUR and EPS, which are based on fossil materials, caused highest environmental impact whereas lowest impact were achieved for the solution which makes use of waste materials. In this study lamb wool was considered as waste material and no production impacts were allocated for it. Lamb wool can be dealt with as waste because some wool types have properties which are not suitable for textile industry and these lambs are bred only for meat industry.
- The optimal consumption of insulation materials depends on building condition and region. In Northern Europe, 300 mm of rock wool still saves a reasonable amount of energy and reduce carbon emissions but in Southern Europe the optimal amount is less than 100 mm (Figure 4 and Figure 5) when both material and heating related impacts are considered.
- In the case of external renovation, where façade is installed with the presence of air gap, different new façade materials can be used. Façade types studied in this survey were concrete, wood and clay brick façades.
    - The best façade material in terms of environmental impacts (carbon footprint, non-renewable raw material and - energy consumption), was wooden façade. This renovation concept is a light weight option, wood is a renewable raw material and timber production utilizes by-product energy which also renewable.
    - In the case of U-value 0.28 W/m2K, the materials' share form CF in Nordic regions was 4 – 20%, but in the case of better insulation (U-value 0.12 W/m2K) it was 30 – 40%. In Central Europe, the materials' share from CF varied between 38 – 52% and in Southern Europe between 58 – 70 %.
- Replacing renovation concept often causes remarkable consumption of materials. In the case of concrete element renovation with outer concrete layer replacement, the amount of new concrete is high. This causes higher carbon footprint compared to the case of 3 layer rendering façade, where the material amount is less.
- Replacing renovation concept with massive concrete and insulation had a carbon footprint value 50 kg/wall m2 which is twice as high as lighter weight renovation option, where rock wool with 3 layer rendering façade is used.
- Materials' share from the total carbon footprint depends on heating energy consumption and heating type.
    - In the regions where heating period is long (Northern Europe), the materials used in wall renovation can cause up to 40% of total carbon footprint (20 year operation). This result refers to a case where mineral wool with 3-layer rendering façade was used and heating energy was produced with the Nordel electricity mix (where renewable energy share is high).
    - For the U-value 0.21 W/m2K, the materials' share from total CF is roughly 10 – 15% but it varies depending on heating types. In the case of U-value 0.1 it is varies between roughly 30 – 40%. The material share can be higher, when high share of heating energy is produced from renewable resources.
    - The material share is much higher in southern Europe where the heating energy demand is much smaller.

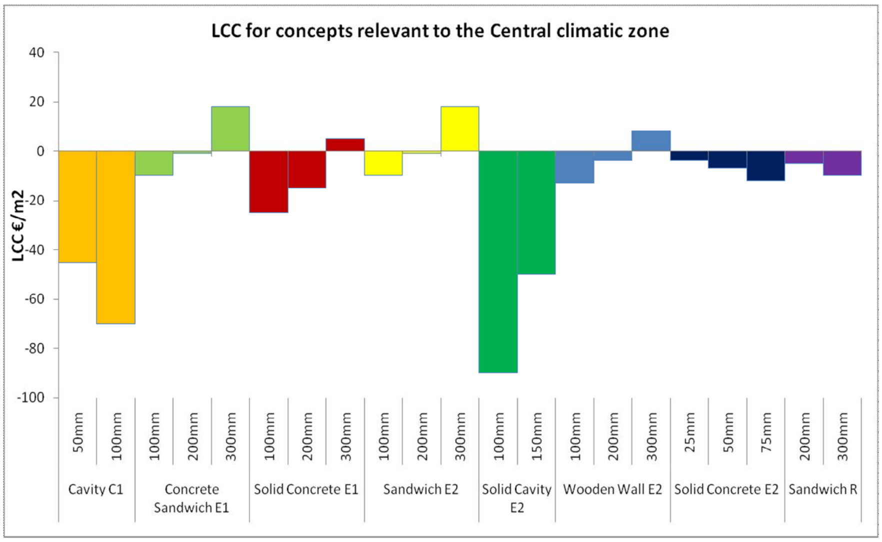
Present study shows that exterior wall renovation can achieve big reduction in energy saving measures and environmental impact. Which renovation option is suitable and best in particular cases should be determined considering the overall building condition, historical background and building neighbourhood and region. Walls form only one part of the buildings and impacts should be assessed also on building level.

Life cycle costing

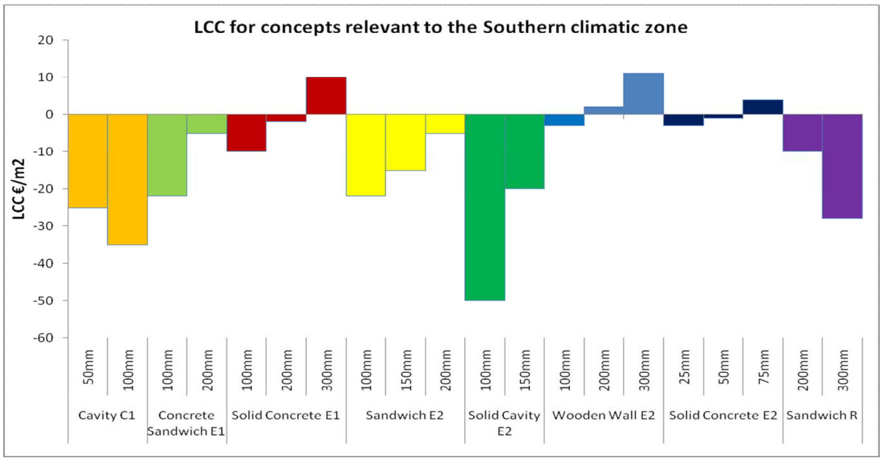
The Life Cycle costing covers only extra costs and energy cost caused by refurbishment. The analysis includes price of money (+ 2%/y). Economic assessment is based on the calculation of life cycle cost according to ISO 15686-5. The results are presented in terms of net present values. This is calculated by summing up the activated costs in different years for present with present unit costs (without discount rate). The energy costs were calculated considering the realistic increase of costs. The present value methodology means summing up of the activated costs in different years for present either with present unit costs or taking the foreseen realized costs (usually energy cost) into account.



LCC for concepts relevant to Northern European climate zone.



LCC for concepts relevant to Central European climate zone.



LCC for concepts relevant to Southern European climate zone.

The refurbishment concepts were compared to a basic case in order to understand more clearly the different effect of material and structure selections. The results show that it is not profitable to improve the thermal insulation of an external wall if the outer layer of the wall doesn't need repair. If the energy price increase rate is high, the refurbishment may become profitable.

When comparing different options, the effect of the decrease of housing area (5% in average) when using internal insulation, has to be taken into account additionally. The costs of refurbishment vary considerably across Europe. Especially the cost of any additional insulation is often non economical. However, the energy saving potential may be very high with a short payback time at least in the cases where an adequate investment support is available.

The best increase in economic value (market value) can be achieved when the building or the block of buildings is located in a relatively valuable neighbourhood and when the whole neighbourhood is refurbished at the same time. In these cases the costs of refurbishment can be compensated with help of the increase of market value. Compensation can also be realised with the help of increasing the density of the area.

Specific refurbishment concepts

The 6 SME partners of the project improved and developed concepts for the refurbishment of exterior walls. The work focused on the chosen common walls types, building types and refurbishment technologies. The research organisations and universities of the project carried out assessments in accordance with the chosen approach.

The wall types included to the company concepts are:

- Lime-sand brick wall; multi rise buildings and single family dwellings Nordic Europe.
- Sandwich element panels; multi rise buildings typical in Nordic Europe.
- Panels with mineral wool; multi rise buildings typical in Russia, Ukraine, Belorussia and Baltic countries.
- Prefabricated solid panels; multi rise buildings typical in Russia, Ukraine, Belorussia and Baltic countries.
- Brick walls with air cavity or decayed wool insulation; single- and multi-storey buildings in North European, Central (also Eastern) European countries.
- Wooden frame wall; detached and terraced house typical in Nordic Europe and also in the Northern Continental Europe.
- Cavity brick walls; single/detached family houses and multi-storey buildings in areas with dry, hot summer; and in areas with cold climate, without dry season and with warm summer.
- Solid thick wall (400–1000 mm) built with two faces of stonework without insulation; single and multi-storey buildings in areas of mild, wet, windy climate.

Altogether 16 refurbishment concepts were developed. The refurbishment concepts developed by the SMEs are listed in the following:

1	Brick wall with ventilation gap and vacuum insulated panel
2	Re-SOLAR (structural solutions collect solar energy and both retain it for the heating and protect the building from overheating)
3	ETICS applied to sandwich element
4	ETICS (External thermal insulation composite systems) applied to sandwich element internal layer
5	ETICS applied to insulated panel RUS (RUS refers to possible areas of application)
6	ETICS applied to solid panel RUS
7	Filling brick wall cavities with carbamide resin foam
8	Thermo-reflective multi-foil outer insulation of brick wall with controllable ventilation air gap before insulation
9	Exterior refurbishment of wooden frame walls with a flex system board insulation
10	Transparent insulation

11	External insulation of solid rubble stone wall with vapour-open natural insulation material and ventilated timber cladding
12	External insulation of solid rubble stone wall with semi-vapour-open mineral wool insulation material and acrylic render
13	External insulation of solid rubble stone wall with expanded polystyrene insulation material and acrylic render
14	External shelter of solid rubble stone wall with unventilated dark-coloured steel sheet cladding
15	Internal insulation vapour-open of solid rubble stone wall with lime-sand pointing outside
16	Load bearing ventilated facade

The following information was developed for all concepts.

- cross section figures of the existing wall
- cross section figures of the refurbishment solution
- material layers and thicknesses
- working methods
- areas of suitable application
- known problems related to refurbishment method
- market potential.

The concepts are presented in SUSREF Deliverable 4.1 and in the Final report Part C.

Usability of the systematic approach

The starting point of the project was that a systematic approach is needed especially for SMEs when they start to improve refurbishment concepts and develop new concepts. The systematic approach was found feasible and useful because it supported the product concept developers to

- iterate and optimize material and structural choices
- compare alternative solutions
- investigate the feasibility of new and innovative solutions
- avoid risks
- assess long-term impacts both from the view point of building performance and environmental and financials impacts
- consider both functionality and process related aspects
- develop systems with help of which clients are supported to set targets for refurbishment works.

During the SUSREF project the systematic approach and the analyses were especially made use of in order to ensure good building physical behaviour, to address risks for low drying capacity or condensation, to define an adequate thickness and right quality of insulation materials regarding energy, carbon footprint and life cycle costs. The method especially supported the developers of concepts to select insulation materials and layer thicknesses considering long term impacts and benefits and to consider risks.

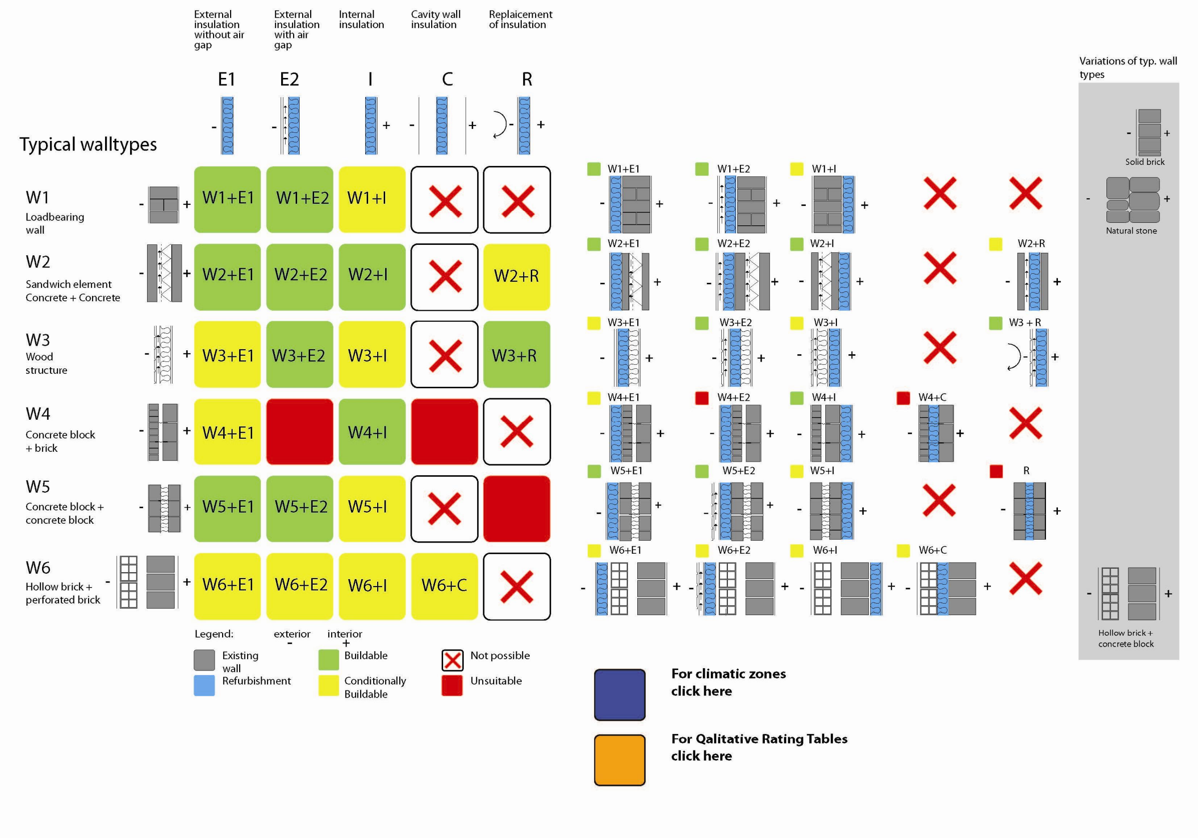
Tools for decision making sustainable refurbishment of outdoor walls

The main objective in developing the tool was to provide an efficient and effective tool for the practitioner, such as the architects, designers and building contractors, in order to identify alternatives for technical solutions for sustainable refurbishment. The developed tool offers quick access to a number of refurbishment solutions studied in the project and leads to detailed information about how suitable and buildable the solutions are. The criteria included in the tool are: Durability, Care and maintenance, Indoor climate, Heating energy, Cooling energy, Renewables, Environment, LCC, Aesthetic quality, Cultural heritage, Structural stability, Fire safety, Buildability, Disturbance, Daylight . Qualitative scales for each of the 15 criteria were prepared and linked to the first level of the tool. See the following table. The table shows an example of a qualitative scale for retrofitting insulation regarding maintenance needs and vulnerability to damage

Score	***The effect of retrofitting insulation***	***Vulnerability to damage***

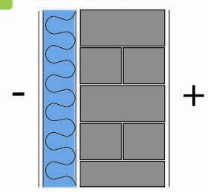
	on the maintenance needs	
-2	Significant aggravation	The need for maintenance and vulnerability to damage of the new facade is significantly higher than for the old facade
-1	Minor aggravation	The need for maintenance and vulnerability to damage of the new facade is somewhat higher than for the old facade
0	No change	The need for maintenance and vulnerability to damage of the new facade is unchanged or almost unchanged compared to the old facade
1	Minor improvement	The need for maintenance and vulnerability to damage of the new facade is somewhat lower than for the old facade.
2	Significant improvement	The need for maintenance and vulnerability to damage of the new facade is significantly lower for the old façade

The 1st level of the tool features a selection of wall types evaluated in the SUSREF project. These are presented on the vertical axis while refurbishment- methods are presented on the horizontal axis. A total of seven wall types were chosen to represent the most commonly used walls in European building stock. The second level presents information about the critical aspects. Level 3 presents the essence of information of each of the 15 criteria. Level four features the whole report containing approximately 300 pages of in-depth information regarding all optional solutions of refurbishment methods.



Level 1

W1+E1



L2: External insulation without airgap

Solid load bearing walls are usually made of bricks or natural stone. Facades made of stone walls may be covered with lime wash, render or other surface treatment. External insulation is the preferred option from a building physical point of view. In wet climates external insulation with airgap is a more robust solution.

REFURBISHMENT CONCEPTS

2	6	8	10	12	13	14		
Re-Solar	T1d	EKK2	ONEKA	SGG2	SGG3	SGG4		

The quality of existing walls must be assessed in terms of current condition showing the need for repairs and suitability. Constructional feasibility is determined by the type of wall, such as large smooth areas vs. more complicated façades. Any kind of exterior refurbishing requires scaffolding and in climates with extensive precipitation tarpaulin is preferable. Domestic or local building cultures should be taken into account as they might constrict possibilities.

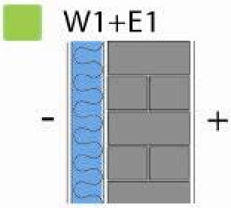
CRITERIA	CRITICAL ASPECTS	MORE INFO
01 Durability	External insulation is generally beneficial for durability of the original construction. Water-proofing details are critical in wet climates. Check actual details against Biological factors; Climatic stresses; Service loads; Dead load.: Solar radiation; Temperature changes; Salt migration; Wetting – drying; Freeze-thaw; Frost damage; Overload; Carbonation; Corrosion; Degradation; Moisture	info
02 Care and maintenance	External layers are subject to damage, particularly using fibrous insulation. A maintenance plan must be included in the control and repair of physical damage. Need for cleaning and coating of surfaces depend on material and local conditions. Replacement of external layer is rarely practical.	info
03 Indoor climate	The solution will reduce air infiltration and may have to be compensated by ventilation. Thermal comfort is improved. The mould risk is reduced, provided that the water intrusion is prevented. Noise from the outside is normally reduced.	info
04 Heating energy	A good solution for preventing heat loss. Thermal bridges are reduced. Consider repositioning windows and doors to minimize thermal bridges. Internal thermal mass is preserved.	info
05 Cooling energy	A good solution for preventing heat loss, reducing cooling loads in hot climates. Internal thermal mass is preserved. In cooler climates cooling energy may increase slightly due to less heat loss at night. External insulation may serve as small, fixed shadings if windows are not repositioned.	info
06 Renewables	Renewable energy sources are not a part of this solution.	info
07 Environment	Environmental impacts are not related to energy use but depend mostly on the actual selection of materials chosen.	info
08 LCC	Depending on the specific solution and construction.	info
09 Aesthetic quality	External insulation will alter the exterior appearance, improving or exacerbating it. Repositioning of windows and doors, insulation of foundation wall and external insulation on adjacent buildings at the same time, can improve aesthetic qualities.	info
10 Cultural heritage	External insulation will conceal or could damage the original exterior of the building. Even when similar surfaces can be recreated, the impression will change.	info
11 Structural stability	Moisture and frost damage of original construction is avoided completely or reduced, ref 01. The load of the external insulation may reduce structural stability.	info
12 Firesafety	Materials must be chosen to give satisfactory fire safety.	info
13 Buildability	Requires space for scaffolding.	info
14 Disturbance	The building can most often be used during refurbishment, but noise, dust, and reduced daylight may disturb inhabitants considerably.	info
15 Daylight	Reduces daylight.	info

SUSREF LINKS (go to the report):

6.1 Framework for planning and decision making

6.2 Framework and recommendations for condition assessment and feasibility studies

Level 2



L3: External insulation without airgap

BUILDABILITY

Current condition of the existing wall
For some types of insulation materials it may be necessary that the surface is even to avoid air gaps between the insulation and the wall alternatively weatherstrip can be used. Insulation materials such as EPS and XPS need an even surface or extra wall finish to be brought flush.

Constructional feasibility
The flexibility of EPS and XPS is lower than for mineral wool making them less able to accommodate irregularities of the surface of the existing wall. The flexibility of vacuum panels is limited since they cannot be cut to fit in any direction. Table: mineral wool – fully flexible (1), EPS/XPS less flexible (-1), vacuum panels less flexible (-2).

Access to the building site
Any kind of external insulation system requires scaffolding. Some kind of outer surface/cladding, e.g. external insulation composite systems (ETICS) are more sensitive to rainfall, hence a tarpaulin is needed. Exterior refurbishment to be painted requires tarpaulin. All work regarding external insulation needs scaffolding, also small houses.

Domestic factors
Factors that may restrict the refurbishment alternatives must be assessed thoroughly. Such factor may be cultural and conservation measures that causes a distinction between interior and exterior insulation.

Climate zones
The choise of cladding and drainage system is of great importance when you have wind driven rain. Wind driven rain has a low score due to lack of ventilation and draining.

Rating[1)] of W1-W6 + E1. Effects on buildability.

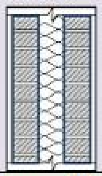
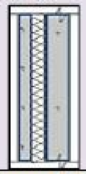
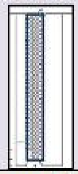
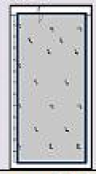
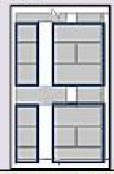
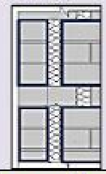
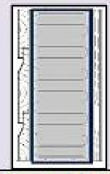
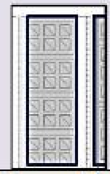
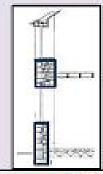
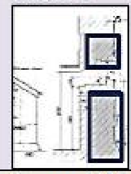
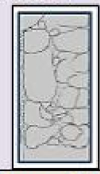
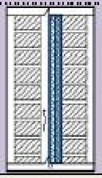
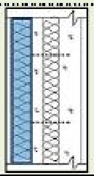
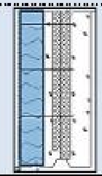
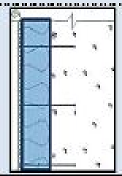
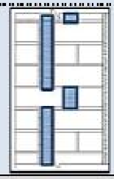
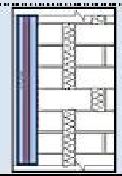
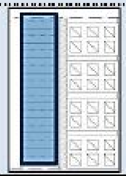
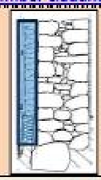
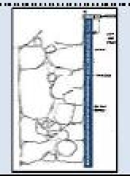
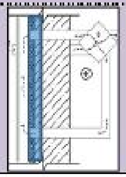
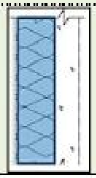
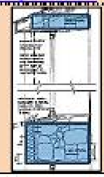
Concept / Parameter	E1 + W1	E1 + W2	E1 + W3[3)]	E1 + W4[3)]	E1 + W5	E1 + W6[3)]
Current condition of the existing wall	0 thr -1	0 thr -1	0 thr -1	0 thr -1	0 thr -1	0 thr -1
Constructional feasibility	1 thr -2	1 thr -2	1 thr -2	1 thr -2	1 thr -2	1 thr -2
Access to the building site	-1	-1	-1	-1	-1	-1
Domestic factors	-2 thr +2	-2 thr +2	-2 thr +2	-2 thr +2	-2 thr +2	-2 thr +2
Climate zones[2)]						
Cfb	1	1	1	1	1	1
Cfbw	-2	-2	-2	-2	-2	-2
Csa	2	2	2	2	2	2
Dfb	0	0	0	0	0	0
Dfc	-1	-1	-1	-1	-1	-1

1) Rating score from -2 through +2, see LEVEL 1, tables for ratings.
2) Climate zones, see LEVEL 1 for climate zones.
3) Conditional suitable according to main table (total judgement).

Level 3

Sets of performance specifications

SUSREF project developed concepts for the refurbishment of exterior walls. The project developed both generic concepts as well as specific concepts. The specific concepts were developed considering specific buildings markets and geographical conditions. The specific concepts are introduced with help of the tool SUSREF SPECIFICATIONS. This document presents the contents and the operating principles of the tool:

Wall types	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11
Name of the existing wall types	Insulated brick wall with no ventilation	Sandwich panel in multi rise buildings	Sandwiched polystyrene in concrete shell	Solid panel in multi rise buildings	Brick wall 430mm with air cavity	Brick wall 430 mm with mineral wool or air cavity	Wooden frame wall	Cavity brick wall	Solid rubble stone wall	Solid thick wall Two faces of stonework	Solid thick wall Two faces of stonework
Cross section of the existing wall type											
Option 1	**Concept 1**	**Concept 3**	**Concept 5**	**Concept 6**	**Concept 7**	**Concept 8**	**Concept 9**	**Concept 10**	**Concept 11**	**Concept 14**	**Concept 15**
Name of the concept	Brick wall with ventilation gap and vacuum insulated panel	ETICS applied to sandwich element	ETICS applied to insulated panel RUS	ETICS applied to solid panel RUS	Filling brick wall cavities with carbamide resin foam	Thermo-reflective multi-foil outer insulation of brick wall with controllable ventilation air gap before insulation	Exterior refurbishment of wooden frame walls – with a flex system board insulation	Transparent insulation	External insulation of solid rubble stone wall with vapour-open natural insulation material and ventilated timber cladding	External shelter of solid rubble stone wall with unventilated dark-coloured steel sheet cladding	Internal insulation vaoour-open of solid rubble stone wall with lime-sand pointing outside
Cross section of the concept											
Option 2	**Concept 2**	**Concept 4**							**Concept 12**	**Concept 13**	
Name of the concept	Re-SOLAR	ETICS applied to sandwich element internal layer	X	X	X	X	X	X	External insulation of solid rubble stone wall with semi-vapour-open mineral wool insulation material and acrylic render	External insulation of solid rubble stone wall with expanded polystyrene insulation material and acrylic render	X
Cross section of the concept			X	X	X	X	X	X			X

Outline of the concepts.

Guidelines for building industry

Mainly on the basis of Task 4.2 outcomes, the project developed guidelines for building industry. The guidelines are presented in Deliverable 7.4 and in SUSRE Final report Part A. The short summary of the guidelines is as follows:

The focus of the work was to pay attention to some of the main findings and results of the previous more thorough technical analysis reports on the refurbishment concepts. The material presented includes summaries and conclusions of several analyses. Only the main results of some topics are given here, the background analysis may be found from the technical reports (mainly report D4.2). These topics have high industrial relevance and the results may be, to a large extent, utilised as recommendations for refurbishment projects. The use of the SUSREF approach is recommended, this approach relates to the following aspects: Durability, need for care and maintenance, indoor air quality, acoustics + thermal comfort, impact on energy demand for heating and cooling, impact on renewable energy use potential, environmental impact of manufacture and maintenance, life cycle costs, aesthetic quality, effect on cultural heritage, structural stability, fire safety, buildability, disturbance to the tenants and to the site and impact on daylight.

As guidelines to the industry when developing concepts for the refurbishment of external walls, the following recommendations are given.

- The building physical performance of the wall has to be checked with suitable methods (as given in D2.2). The main principle of designing and constructing external wall structures is that the wall must be airtight and the water vapour permeability of structural layers increases gradually towards the outside surface of the wall. A water vapour barrier may be needed near the inner surface of a wall.
- With regard to durability aspects of the wall, driving rain water leakages into wall structures are harmful. Water may enter the wall through connections, construction faults or during unprotected construction work. If the insulation material is foam plastic or other water vapour tight material or if the insulation material is such that can absorb very little moisture, or if there is no ventilation gap behind the façade, water leakages are very risky. Excessive moisture levels may cause mould to develop in the wall. This may be a risk considering also the indoor air quality.
- With regard to fire safety, to reach the intended fire safety level for multi-storey buildings, it is recommended to use non-combustible (=A1 or A2-s1, d0 reaction to fire class) or at least B-s1, d0 class external boards/layers. In case of combustible insulation, the boards should be thick enough to protect the insulation.
- With regard to structural stability the assessment of the load bearing capacity of the existing walls must include a verification to ensure that it can withstand the mounting of fastening points. Changes in water drainage, changes in humidity and danger of frost heave etc. may affect the structural stability in the long term.
- With regard to buildability, the aspects which need to be checked are the needs of space, availability of materials, work force, quality of workmanship. These will depend on the project at hand and on the local conditions.
- With regard to energy saving, the effect of the placement of the insulation on the heating demand can be studied with a dynamic simulation. It is however possible to estimate roughly the effect of the insulation on the heating demand with simple stationary calculation techniques such as the heating degree day method, this gives an upper limit value on the possible energy saving. The façade insulation may reduce the heat gain during cooling periods, up to a value of 75%. For hot Mediterranean climates such reductions can be directly converted into cooling load reductions. However walls also affect the thermal capacity of the building, and thus, internal insulation can lead to a reduction of the effective thermal capacity. These cases can only be properly addressed by direct dynamic modelling and simulation of the whole building.
- From the environmental impact viewpoint, the refurbishing of external walls is usually beneficial; the environmental impact of the materials is less than the impact of the saved energy, up to a certain limit.

- Considering the life cycle costs, refurbishing actions are most beneficial to be carried out at a time point when the wall needs maintenance work anyway.
- Also the other aspects not specifically mentioned above (- need for care and maintenance, - indoor air quality, - acoustics and thermal comfort, - aesthetic quality, - effect on cultural heritage, - disturbance to the tenants and to the site, - impact on daylight) are important to be considered.

Recommendations for standardisation bodies

The aim of the project was also to study and summarise relevant standards for sustainable renovations that might need revision and recommendations for standardisation bodies. Relevant standards are in the fields of

- environmental assessment of building products and buildings,
- life cycle costing,
- service life assessment.

Relevant standards which might need revision

Product level standards

CEN Technical Committee TC 350 has worked out product level environmental declaration standards including product category rules, communication format from business to business use and methodology for the selection and use of generic data in the LCA and EPD use. The standards are: EN 15804, CEN/TR 15941:2010 and EN 15942:2011. Principally these standards are applicable for all building materials and components including refurbishment and renovation materials and components.

SUSREF recommends clarifying the terms functional unit and building performance, when these standards are applied for products and components which are meant for building refurbishment and renovation use. Primary purpose of the functional unit is to provide the reference for comparability of LCA data. It may be difficult to define what the functional unit in renovation is. We recommend that the functional unit in the context of building refurbishment is defined so that it is the building or its part refurbished to fulfil the intended performance. The intended performance of the refurbished building or building part can be achieved with different kinds of technical refurbishment concepts which may have variable life cycle impacts both in terms of costs and environmental loadings.

EN 15804 defines EPD types regarding the life cycle stages covered. In the case “cradle to grave” all life cycle stages are covered: product stage, construction process stage, use stage, end of life stage. Use stage covers also modules for maintenance, repair, replacement and refurbishment. These stages should be clarified by taking into account potential additional service life with certain repair and refurbishment concepts or products (longer service life and better performance).

Service life assessment

Service life assessment is an important part for life cycle assessment of new buildings. The assessment can be based on the service life planning standard ISO 15686 which includes several parts. These standards are mainly applicable for new buildings. For existing buildings the remaining service life should be estimated on the basis of the inspection of the condition of materials and products by experts. While there are relevant standards for service life predictions for materials and components in general and some material specific standards, there no international standards for assessing the condition of whole buildings. Such a standard should provide a framework for the assessment and reporting building condition in different situations.

Remaining service life depends on realization of scheduled care and maintenance but also on the quality of possible previous refurbishments. When refurbishment includes replacements, the service life assessment should be performed according to the existing service life planning standards. Refurbishment project may also save some parts from existing structure and install additional parts. These measures may cause significant changes in environmental conditions such as moisture and thermal conditions. No standardized method for service life assessment of the remaining service life of these existing building components exists.

The recommendation is to prepare

1) a standard for assessment of building condition,
2) a new service life standard which takes into account the condition of existing building and gives exact instructions for the assessment of remaining service life for building refurbishment.

Life cycle costing

There are international standards and methodologies concerning Life cycle costing. As standardisation mostly concerns terms, process and calculation schemas, the existing standards can be applied both for new construction and renovation. There is no need for any new standards for life cycle costing of refurbishments but the methodological framework for calculating cost-optimal levels of energy performance requirements for new buildings and building elements must be formulated also for extensive energy-intensive renovations.

Euro codes for design

Euro codes are European-wide standardized calculation rules for Building industry. CEN supervised and/or approved those. They have many advantages containing uniform design criteria, harmonizing different national rules and having uniform basis for research & development.

SUSREF project recommends the development of a new Euro code which takes into account refurbishment aspects of building envelope and frame. We recommend the development of a Euro code “Design for refurbishment of external walls” which describes design methods and performance criteria. Proposal for the content topics are as follows:

- Diagnostics,
- performance criteria according to SUSREF aspects,
- use of different materials (including recycled materials) and their interactions,
- assessment and calculation method for example as in SUSREF Deliverable 2.2,
- renovation concepts,
- details for refurbishment (good construction practice),
- execution of work,
- service life design.

CE-marking and product approval

The Construction Product Regulation (CPR) has been adopted by European Commission in 2011 and it replaces Construction Product Directives. The adoption of CPR allows construction products that have been assessed against harmonised standards to be legally placed on the market anywhere in the European Economic Area. Products are fit for their intended use if they comply with a Harmonized Standard, a European Technical Approval or a non-harmonized technical specification recognized at EC level. The CE marking is based on a harmonised product standard (hEN) or a European Technical Approval (ETA). The European Technical Approval granted only by a member body of the European Organisation for the Technical Approvals, EOTA.

Building materials used in renovation and refurbishment are CE-marked now according to the same rules as the products used in new constructions. A condition of the CE marking is that the product has been subject to the appropriate conformity assessment procedure. This consists usually either of the certification of conformity of the product or the certification of the factory production control and/or testing, carried out by a third party. The product-related requirements are described in the relevant technical product standard or ETA. For the harmonized standards to be relevant for refurbishment work, it is necessary that the “intended use” of the product includes refurbishment and that all relevant material properties are declared.

European Technical Approval (ETA)

A European Technical Approval (ETA) for a construction product is a technical assessment of its fitness for an intended use. This bases on the contribution made by this product to the fulfilment of the seven Essential Requirements, as stated in the Construction Product Regulation for the construction works in which the product is installed. European Technical approval is the parallel activity for the products which don't have relevant harmonized Standards for showing their conformity for essential requirements.

According to the European Organization for Technical Approvals (EOTA) they comprise the Approval Bodies nominated to issue European Technical Approvals (ETAs) by EU Member States and EFTA. The role of EOTA is primarily to monitor and progress the drafting of ETA Guidelines (ETAGs) and to co-ordinate all activities relating to the issuing of ETA's. The ETA Guideline (ETAG) is a basis for ETA's, i.e. a basis for technical assessment of the fitness for use of a product for an intended use. An ETAG is not itself a technical specification in the sense of the Construction Product Regulation, but commonly ETAG guideline exists prior to European Technical Approval for the relevant product. ETAG comprise a list of the relevant Interpretative Documents, the specific requirements for the products within the meaning of the Essential Requirements1, the test procedures and the methods of assessing and judging the results of the tests, the procedures related to the Attestation of Conformity and also the period of validity of the approval.

Recommendation is to set up ETAG guidelines for renovation materials and concepts. The basic aim of this ETAG is to establish how Approval Bodies should evaluate the specific characteristics/ requirements of a product or family of products used in refurbishment and renovation.

Recommendations for policy makers

The recast directive on energy performance of buildings forms a strong basis for the regulation and steering of energy performance of existing buildings and building renovations. In July 2012 all Member States should have adopted and published the laws, regulations and administrative provisions necessary to comply with Articles 2 to 18, and with Articles 20 and 27. These include the requirement to take the necessary measures to ensure that when buildings undergo major renovation, the energy performance of the building or the renovated part thereof is upgraded in order to meet minimum energy performance requirements set so far as this is technically, functionally and economically feasible. In addition, the energy performance certificate will include recommendations for the cost-optimal or cost-effective improvement of the energy performance of a building or building unit. The recommendations included in the energy performance certificate shall cover measures carried out in connection with a major renovation of the building envelope.

The fragmented structure of the building sector and the huge spectrum of technical solutions and technical quality of existing buildings and building envelops means a big challenge for the successful implementation of the extensive refurbishment of exterior walls of the European building stock.

In addition to the coming legislation and regulations that will be based on the recast energy performance directive, there is also a need to develop other instruments than control and regulatory instruments. Especially fiscal instruments and incentives and informative support will be needed in order to

- to achieve common willingness among public to make efforts for significantly improved quality and energy performance of exterior walls of buildings
- to avoid risks in the connection of building renovations
- to economically facilitate choices that are excellent from the view point of technical and long-term sustainability reasons.

Especially SUSREF recommends the following measures for steering sustainable refurbishment:

(a) development and adoption of methods of consultation steering

1 Essential requirements according to CPR are mechanical resistance and stability, safety in case of fire, safety and accessibility in use, hygiene, health and environment/emission to indoor air, protection against noise, sustainable use of natural resources, energy economy and heat retention, Hygiene, health and the environment/Emissions to air.

The development of the ability of planning authorities and building permit authorities to provide more supportive guidance and consultation would facilitate the finding and utilization of refurbishment solutions that are beneficial and advanced from the view point of energy performance and overall sustainability. This is especially important in the current situation where a big number of existing buildings will be renovated and much new information about the sustainable refurbishment concepts of exterior walls is needed. On the other hand, the building authorities – considering their role in the process – want to avoid a situation where their give guidelines or recommendations about the use of specific solutions. Thus the availability of recognized standards and design guidelines is emphasized.

(b) reinforcement of informative support and dissemination of information about sustainable refurbishment concepts on national levels

The structure of the building sector is fragmented and there is an extremely large number of actors and large inhomogeneity of actors involved in building processes. Therefore, the information that has been developed on European level about the sustainable refurbishment concepts of exterior walls does not easily reach all actors that would need this information. There is a need to develop the availability of information about refurbishment concepts which are relevant in national context considering the climatic conditions and the quality of the existing building stock. This information should be made available so that designers and other actors would easily access it for example through easy-to-use data bases. However, the reliability of information should be ensured and – on the other hand – the trust on the good quality of information should be ensured by placing the information on web-pages of recognized local actors that deliver and disseminate guidance for building and construction.

Significantly improved energy performance of exterior walls requires increased layers or improved qualities of insulation materials. The improved energy performance of exterior walls should not course any problems in the building physical behaviour of walls and all risks with regard to moisture and mould growth should be avoided. The development of guidelines for building physical assessment and the development of information about the durability of refurbishment concepts was one of the focuses of SUSREF project and much information is available. However, it still recommended to cross-check whether there is any need to carry out more detailed studies about the potential risks of refurbishment concepts (including new materials and technologies) and need to develop more detailed guidelines for safe and sustainable concepts. These should be done considering the local conditions and local methods of construction. For example the Finnish Ministry of Environment has recently contracted to VTT a research which makes detailed and thorough investigation about the avoidance of moisture risks in the context of very efficient heat insulation of exterior walls in Finland.

(c) development of effective incentives for sustainable refurbishment of exterior walls

The implementation of the recast Energy performance directive will ensure the consideration of energy performance when buildings undergo major renovation. The energy performance of the building or the renovated part must be upgraded in order to meet minimum energy performance requirements so far as this is technically, functionally and economically feasible. In order to accelerate needed renovations and to avoid situations where needed renovations are much delayed because of financial reasons, effective incentives are needed. The necessary renovations are often delayed and the selected refurbishment methods are sometimes chosen on the basis of financial reasons that may be short-term and imprudent but – on the other hand - important from the view point of the financial capacity of some building owners or tenants. Therefore, rightly directed incentives may considerably promote and speed up renovations that significantly upgrade the energy performance and sustainability of exterior walls.

(d) promotion of training for improved expertise in design and construction of sustainable refurbishment concepts

Different kinds of measures are needed in order to ensure the dissemination of information to a large group of actors that will need improved knowledge about sustainable refurbishment of exterior walls and sustainable renovation of buildings. The specific consideration of the topic should be ensured both in university and polytechnic schools as well as in training courses provided by associations of designers and by building industry.

When looking at the skills and knowledge that are delivered by the training and education institutes in some European countries, the syllabus and knowledge areas taught focus mainly on the new build sector, and there is lack of specific courses that deliver specific and detailed knowledge on the refurbishment sector of energy efficiency. If this scenario is replicated across the EU, significant steps to remedy the situation should be undertaken. For the professional bodies involved in refurbishment it is important that the practitioners have at least a rudimentary understanding of the certain areas.

(e) continuous support for demonstration

Different kinds of measures are needed in order to ensure the dissemination of information to a large group of actors that will need improved knowledge about sustainable refurbishment of exterior walls and sustainable renovation of buildings. The specific consideration of the topic should be ensured both in university and polytechnic schools as well as in training courses provided by associations of designers and by building industry.

Demonstration projects initiated or supported by the authorities may be very effective in promoting sustainable refurbishment of buildings. Demonstration projects should also be considered as resources for training and knowledge transfer. In addition to demonstration projects with a high ambition level, also moderately ambitious projects should also be demonstrated. There is a need to demonstrate widely affordable and feasible refurbishment projects. In order to ensure that the achieved results and valuable knowledge is usable also in other projects, demonstration projects should be thoroughly documented. Documentation of projects should also be comparable. Demonstration of sustainable property managements would also be needed. While technologies for sustainable building construction and refurbishments need to be further developed and demonstrated, it is at least as possible to demonstrate how these technologies and processes can be incorporated in a sustainable property management practice.

(f) citizen engagement

Tenants and building owners living in buildings are the end-users of new technologies for building refurbishment. The increase of public awareness of the importance of sustainable building through information campaigns is also needed. One of the biggest barriers for the quick promotion of sustainable building is the low level of knowledge and awareness in the areas of energy by the end user. Launching information campaigns on new energy saving technologies and renewable technologies (which at the same time fulfil the overall requirements of sustainable building as explained in Section 3.2) might help to overcome the distrust by public on the sustainable refurbishment technologies especially when this happened simultaneously with the provision of effective incentives.

Potential impact, dissemination activities and the exploitation of results

SUSREF has developed

- information about the potential impact of the refurbishment of exterior walls,
- concepts for the refurbishment of exterior walls,
- a systematic approach for the assessment and comparison of concepts
- guidelines for refurbishment processes and for building industry
- recommendations for standardisation bodies and policy makers.

The potential impact of the project will be based on the use and exploitation of these outcomes.

<u>Assessed potential impact of the refurbishment of exterior walls on the European level</u>

SUSREF aimed at making a realistic assessment about the potential impact of the refurbishment of exterior walls. SUSREF assessed on the bases of calculation that that the total CO2equ saving for the single family houses in Europe is 55.4 Mt and for the multi-story buildings 16.8 Mt per year. Thus in total the assessed saving is 72 Mt during 2011–2020 per year. This was calculated on the basis of U-value changes and heat degree days by using the proposed refurbishment concepts by the SUSREF partners from different parts of Europe and by using realistic assumptions about the rates of refurbishment.

SUSREF assessed the potential savings in energy and costs with help of using scenarios for the refurbishment of external walls. According to the basic concept (based on certain assumptions about the proportion of buildings which could undergo different kinds of refurbishments (internal, external or cavity wall insulations or extensive refurbishments)) 30% of the residential building stock will be refurbished during the next 10 years. The total investment cost was assessed to be 28 000 million euro/year allocated to the energy related refurbishment. On the other hand, the savings in energy costs were assessed to be 2 500 million euro/year. It was calculated that the change in annual Life Cycle Cost is in average -11 000 million euro within 20 years. In addition, it was assessed that the corresponding increase of labour would be 396 000 man years per year. It was also assessed that in the case of strong support (with help of different kinds of steering instruments) for refurbishment the corresponding figures might increase by 25%.

<u>Business strategies of the SME partners</u>

The first phase of exploiting the project outcomes will take place in the SMEs involved in the project.

SMEs have worked out their business strategies. The SMEs created business plans in order to meet the SUSREF goals of dissemination of the R&D results and to take up the results in the businesses of the partners and wider industry delivering either services or producing materials, components or other tangible solutions for sustainable façade refurbishments in various parts of Europe. With a business plan the entrepreneurs analysed the strengths and weaknesses of their own capabilities. The business plan works for a business to look ahead, allocate resources, focus on key points and prepare for challenges and opportunities.

SUSREF has developed knowledge, methods and concepts that can be utilized as expert services offered in the façade structure condition surveys:

- Energy and circumstance simulations

- Life cycle assessment
- Building physics assessment
- Facade renovation services
- Facade renovation designs

These services can be integrated into SME´s assignments in the future or can be sold separately.

The use of the expert services is not limited solely to the sector of residential buildings but can be exploited in buildings in general.

Sustainability is one of the main targets in development. Customer, owner and inhabitant want to have a healthy living environment. Because of increasing energy costs our clients need energy efficient buildings. The client needs solutions which take into consideration the technical functionality and economy. The need for the services will be for the whole lifecycle of the building e.g. for the following reasons:

- changes of the owners of the buildings
- changes of the users of the buildings
- changes in legislation

The new concepts enable better energy performance and lower risks. Some SMEs searched for solutions for reduced costs. The developed new concepts help to simplify the process and reduce these problems.

SMEs also assessed that they will be able to differentiate from competitors with the help of refurbishment concepts.

The clients of the SMEs are house owners, inhabitant associations, property owners, construction companies, developers etc. The target market for specialist services will be at the beginning the countries they already are active. These also include countries outside the EU especially Russia and also Middle East and India.

<u>The implementation of the systematic approach</u>

The implementation of the systematic approach for the development of new concepts and for the development of expert services will require wide expertise in SMEs. Thus the implementation of the proposed process fits best for enterprises that not very small.

On the basis of the experiences, the systematic approach was found feasible and useful because it supported the product concept developers to

- iterate and optimize material and structural choices
- compare alternative solutions
- investigate the feasibility of new and innovative solutions
- avoid risks
- assess long-term impacts both from the view point of building performance and environmental and financials impacts
- consider both functionality and process related aspects
- develop systems with help of which clients are supported to set targets for refurbishment works.

During the SUSREF project the systematic approach and the analyses were especially made use of in order to ensure good building physical behaviour, to address risks for low drying capacity or condensation, to define an adequate thickness and right quality of insulation materials regarding energy, carbon footprint and life cycle costs. The method especially supported the developers of concepts to select insulation materials and layer thicknesses considering long term impacts and benefits and to consider risks.

All of the SMEs have agreed that this systematic approach is of interest to them to demonstrate the costs to the clients, statutory authorities, contractors etc. Also these systemised tools can save times by avoiding works on inappropriate upgrades. In UK this systemised approach would not benefit much as the architects firms or small SMEs are of 1-5 person, so the job of small size can be handled by a single person only, however in other countries they have suggested that many SMEs including Energy auditors, technicians, project managers and architects would benefit by using this systemised approach at the beginning of their project. Tools like WUFI, LCC, LCA can be very useful in the beginning of the design process because it will quickly estimate the effectiveness of the chosen solutions in a particular climatic zone.

Dissemination of results

The main methods and activities with the help of which the outcomes of the project are disseminated are as follows:

Business strategies and business activities of the SME partners of the project

With help of the developed business strategies and new business activities, the SMEs of the project will

a) adopt new concepts, new processes and new services, and
b) disseminate the information about new services and concepts when networking and doing business.

New research foreground of the research institutes and universities

The outcomes of the project will be made use of in on-going and coming research projects and contract projects.

For example VTT will utilize and disseminate SUSREF results in the current group of projects "Ownership in sustainable building" (OKRA) which develops new processes for municipalities and owners when they want to support both professional as well as small builders in sustainable renovation and refurbishment. The aim is to develop for cities processes for consultative steering which encourages builders to adopt sustainable and energy efficient concepts for building renovation.

SUSREF Workshops

The outcomes of the project have been introduced and discussed in workshops in the UK, Spain, Norway and Finland. In all of these workshops a remarkable number of important stakeholders participated, listened to the results and participated to the discussion about how to further disseminate results.

Other workshops

The results have also been introduced in other workshops and seminars. Especially the topic "Historical buildings" has been much highlighted:

List of presentations made during SUSREF research project, reporting on interim findings.
Frances Voelcker for Sustainable Gwynedd Gynaladwy:

Date	Audience	Title/Content
04 Feb 2012	Tanygrisiau Energy Day: Householders, housing association welfare officers, other energy advisers	SUStainable REFurbishment of Existing Facades (bullet point text summary; many illustrations)
05 Dec 2011	SUSREF workshop: Practitioners, housing association managers, contractors, conservation authority surveyor	Site work practicalities: where the theory ends
28 June 2011	Society for the Protection of Ancient Buildings Technical Day	Update on SUSREF
26 May 2011	Plas Tirion Training day: practitioners and contractors, conservation authority	Conservation of Energy and Building Fabric in Pre-1919 Buildings: The rationale and the practicalities
16 Nov 2010	Llandeilo Traditional Sustainable Building Centre: Conservation of Energy and Building Fabric in Pre-1919 Buildings	Introduction to SUSREF
05 Oct 2010	SGG Annual General Meeting	SUSREF
29 Sep 2010	Society for the Protection of Ancient Buildings - Technical Day: Historic building owners, architects, contractors, conservation bodies	Introduction to SUSREF

Recommendations

SUSREF has developed guidelines and recommendations for building industry, standardisation bodies and policy makers. The project has not succeeded well in disseminating these recommendations but it is still searching for possibilities and support in dissemination. The recommendations for standardisation bodies have been given to the representative of the Confederation of Finnish Construction Industries and its president for building regulations and standardisation to be further promoted in international networks and organizations.

The also asks support from the project officer in order to find suitable contacts to disseminate the recommendations for policy makers.

Teaching and education

The results from the SUSREF project are being presented to students in Cardiff University engaged in postgraduate studies at Masters and PhD level in the general areas of building and sustainability. Cardiff University is currently developing plans for a Masters in Building Conservation which will incorporate findings from SUSREF research as a major component.

Training courses

The research organizations VTT, TECNALIA, BRE and SINTEF and their staff often participate as lecturers in different kinds of training courses. The researchers will utilize the project material and disseminate results in coming events which train professionals in sustainable renovation and refurbishment. Because of the importance of the matter, these events will be many during the coming years.

Scientific articles

The project researchers have written manuscripts for scientific articles and conference papers. This is the best route to disseminate the results for the research community. Existing article and papers for refereed journals and conferences are as follows:

Tarja Häkkinen, Systematic method for the sustainability analysis of refurbishment concepts of exterior walls, Manuscript submitted to Construction and Building Materials, Reviewed and preliminary accepted with a request for few changes, Changes made and manuscript resubmitted

> Abstract: Because of the age of the European building stock and because of the new energy performance regulations, safe and efficient concepts have to be developed for the refurbishment of exterior walls. The objective of this paper is to explain the method that was developed in the European SUSREF project for the analysis of refurbishment concepts, and describe how the method was effectively implemented during the project. Both generic refurbishment concepts and company specific solutions were developed for the refurbishment of building external walls. All concepts were systematically assessed with help of the method. The method includes a list of performance criteria and detailed guidelines for the assessment. Important aspects include not only the aspects of technical and functional performance but also process related aspects and life cycle aspects. The process related aspects should not be limited to technical feasibility but also consider the impacts caused to neighbouring buildings and their users. Life cycle aspects should cover both environmental as well as financial aspects. The approach was tested during the project and it was found suitable both for the development of new innovative solutions as well as for the improvement of more conventional solutions. The approach is also recommended to be made use of in the development of design codes for refurbishment concepts of exterior walls. A systematic method should also be used in the dissemination of information about recommended refurbishment concepts for designers.

Tomi Toratti et al. Durability considerations of refurbished external walls. A manuscript to be be submitted to Construction and Building Materials

> Abstract: This paper draws attention to some of the main findings and results of the European project: Sustainable Refurbishment of Building Facades and External Walls. The material presented includes only some analyses cases which were carried out during the project. This topic has a have high industrial relevance and the results may be, to a large extent, utilised as recommendations for refurbishment projects.
> In planning of a refurbishment, there is no point to try to prolong the service life of the original concrete core if the limit state of the service life has already been reached at the time of refurbishment. The extending of service life is only reasonable by a coating if the carbonation has not reached the depth of reinforcement.
> Careful planning is necessary to assure good performance of the refurbished sandwich walls. The original structure and its condition should be assessed because a successful planning is only possible when the materials and possible deterioration of the original sandwich wall is known. The risk of mould growth should be considered when using dense insulation materials, such PUR. If the original outer concrete core would be replaced together with the original insulation, this would seem to be relatively risk free. However, in cold weather countries the risk of frost attack should always be considered with concretes and mortars. Also the use of dense coatings on the original outer core or rendering may cause a long lasting mould risk.
> As guidelines to the industry when developing concepts for the refurbishment of external walls, the following recommendations are given.
> The building physical performance of the wall has to be checked with suitable methods. The main principle of designing and constructing external wall structures is that the wall must be airtight and the water vapour permeability of structural layers increases gradually towards the

outside surface of the wall. A water vapour barrier may be needed near the inner surface of a wall.
Considering durability aspects of the wall, driving rain water leakages into wall structures are harmful. Water may enter the wall through connections, construction faults or during unprotected construction work. If the insulation material is foam plastic or other water vapour tight material or if the insulation material is such that can absorb very little moisture, or if there is no ventilation gap behind the façade, water leakages are very risky. Excessive moisture levels may cause mould to develop in the wall. This may be a risk considering also to the indoor air quality.

Erkki Vesikari R.M. Ferreira. Simulation technique for service life assessment of façade refurbishment. A paper submitted to IALCCE conference. Third International Symposiun on Life-Cycle Civil Engineering. October 3 – 6.2012. Vienna Austria

ABSTRACT: The EU Research Project SUSREF proposes as its outcome sustainable concepts and technologies for the refurbishment of building facades and external walls. One of the tasks in the SUSREF project was to predict the performance and service life of the proposed refurbishment concepts.
A simulation software developed at VTT in the 1990s was updated and used to evaluate possible degradation in refurbished concrete facades. The software is able to emulate the temperature and moisture content in a cross-section of a sandwich wall and to apply temperature and moisture sensitive degradation models at critical points of the wall throughout its service life. Five different refurbishment concepts of building facades were analysed for predicting possible moisture and degradation problems. The analyses were conducted in various European climates and with various materials as thermal insulation and outer core.
The results show that the risk of mould growth and continued corrosion of reinforcement should be considered when using dense insulation materials, such as expanded polystyrene and polyurethane. The concepts where the original outer core and thermal insulation are replaced by new ones seem to be relatively risk free. In addition, in cold weather countries the risk of frost attack should always be considered with concretes and mortars. The use of dense coatings on original outer core or rendering may increase the mould risk.

Erkki Vesikari and R.M.Ferreira. Service Life Assessment for refurbishment concepts of concrete façades. fib Symposium: Concrete Structures for Sustainable Community STOCKHOLM 2012 11-14 June 2012 Royal Institute of Technology (KTH) Stockholm, Sweden

Abstract: The EU Research Project SUSREF proposes new sustainable concepts and technologies for the refurbishment of building facades and external walls. As one part of the project it was necessary to identify the volumes of needs of refurbishment in the EU and in neighbouring areas and to evaluate the meaning of this in terms of environmental and economic impact and business potential. Within the tasks of the SUSREF project was also the service life assessment of the proposed refurbishment concepts of building facades and external walls. A simulation software, developed at the Technical Research Centre of Finland, was used to assess the performance and possible durability risks of the refurbishment concepts. The simulation software is able to emulate the temperature and moisture variations in a cross-section of the wall and to apply temperature and moisture sensitive degradation models at critical points of the structure. The software was applied for analyses of the refurbishment concepts in several European climates and with various material options. In this paper some results of the analyses are presented.

SUSREF Publications

The main results of the project are also reported in three publications which are available on the VTT web site:
http://www.vtt.fi/publications/?lang=en

The VTT publications register is available also via WWS, the worldwide portal of science and research publications.

The final reports of the project are as follows:

- Sustainable refurbishment of exterior walls and building facades. Final report Part A. VTT Technology 30. Espoo 2012
- Sustainable refurbishment of exterior walls and building facades. Final report Part B. VTT Technology 33. Espoo 2012
- Sustainable refurbishment of exterior walls and building facades. Final report Part C. VTT Technology 36. Espoo 2012

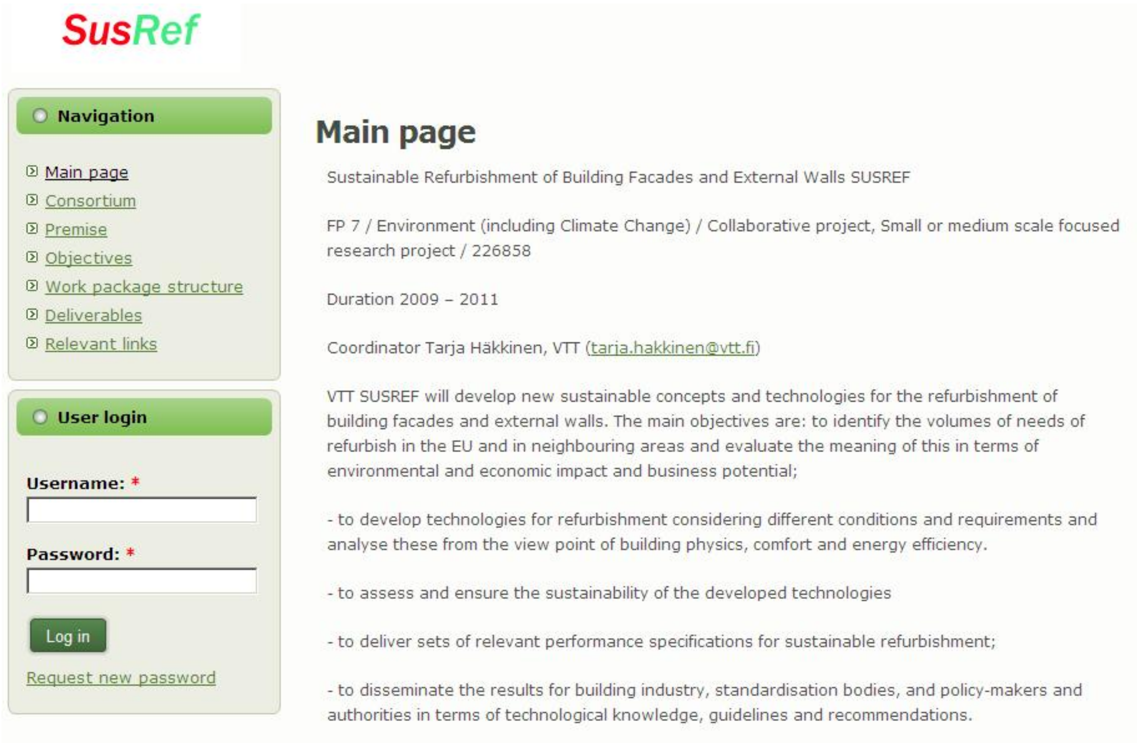
Papers to be submitted to regional SB conferences in 2013

The project group will also disseminate results by submitting papers to the European regional sustainable Building conferences that will take place during 2013. Especially the following conferences will be considered:

- SB13 Munich Germany, April 2013
- SB13 Graz Austria, September 2013
- SB13 Oulu Finland, May 2013.

SUSREF web page

The project has a web page where all SUSREF deliverable are available. VTT will maintain the page and offer all project research outcomes for use for related coming research projects.
http://cic.vtt.fi/susref/



SUSREF TOOL and SUSREF SPECIFICATIONS

The SUSREF Tool and SUSREF Specifications are available on the projects web site.

The purpose of these tools is to enable building professional and designers to make use of the SUSREF refurbishment concepts and search information about the suitability of alternative concepts.